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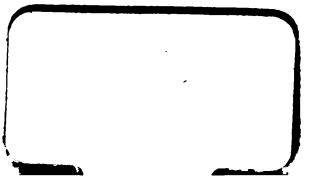

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THE MINERALOGICAL MAGAZINE

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No. 41. APRIL, 1890. Vol. IX.

The Hemimorphism of Stephanite: the crystalline form of Kaolinite.

By H. A. Miers, M.A.

[Read November 5th, 1889.]

(*a*). *The Hemimorphism of Stephanite.*

STEPHANITE has been the subject of two important memoirs. Schröder[1] examined minutely the crystals from Andreasberg; Vrba[2] has described fully the character of the stephanite from Przibram and other localities, and has given at the same time a summary of the observations of previous mineralogists, so that his memoir constitutes a monograph of the mineral.

By neither of these observers, however, nor elsewhere, has it been stated that stephanite is hemimorphic, although it has been suspected of being possibly hemihedral.

It is the object of the present paper to establish the hemimorphism of

[1] *Pogg. Ann.* 95 (1855), p. 257.

[2] *Ber. Böhm. Ges.* (1886), p. 119.

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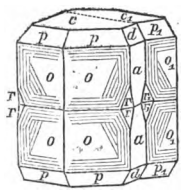
stephanite upon evidence similar to that which has been employed in the case of pyrargyrite.

With regard to the latter mineral it has been shown by M. Schuster[1] and myself[2] that certain striæ upon the prism faces are unsymmetrical since they point to one end of the crystal alone; and further, that when they occur at both ends they are accompanied by certain indications of twinning which show the crystal to be in reality a combination of two hemimorphic prisms attached to each other by their similar ends. This twinning tends to disguise the hemimorphic character of the crystals.

A similar striation and the same mode of twinning may now be shown to exist in stephanite.

The accompanying figure represents a combination of the forms :—



$c = 001 = oP$
$a = 100 = \infty \breve{P}\infty$
$o = 110 = \infty P$
$d = 201 = 2\breve{P}\infty$
$P = 111 = P$

twinned upon the face $\bar{1}10$: the two individuals are combined parallel to the twin-plane which is indicated by the dotted line upon *c*.

The faces *c* *P* and *d* are generally smooth and bright, except when traversed by twin laminæ parallel to faces of the forms $110 = \infty P$ and $310 = \infty \breve{P}3$; the brachypinakoid *a* is striated horizontally and vertically.

The prism *o* is sometimes smooth and sometimes striated horizontally and vertically; but on the crystals which are the subject of the present note, it is characterised by an oblique striation of special significance inclined at an angle of 23° 21½′ to the prism edge.

If now the attention be confined to the upper half of the figure, it will be seen that these striæ are exhibited upon each face of the prism *o*, and that they run in one direction parallel to its intersections with the form $\Gamma = 731 = 7\breve{P}\frac{7}{3}$.

The lines are only parallel to those faces of Γ which are situated at the lower end of the prism, and are therefore sufficient in themselves to indicate a want of complete symmetry; but the hemimorphic character is more clearly displayed when the form Γ is developed and presents small bright planes which are then to be found at one end of the crystal alone.

The figure further illustrates another feature which is characteristic of

---

[1] *Zeits. f. Krystallographie* 12 (1887), p. 117.

[2] *Min. Mag.* vii. pp. 71, 79, and *Zeits. f. Kryst.* 15 (1889), pp. 160, 168.

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most, though not of all, of the hemimorphic crystals. The middle of the prism is traversed by a line of junction parallel to the basal plane c, dividing the crystal into two symmetrical halves. The upper half has oblique striations parallel to the faces of Γ situated at its lower end; the lower has the striations parallel to Γ at its upper end; so that these faces when present give rise to small re-entrant angles at the junction of the two individuals.

Such crystals must be regarded as twins precisely similar to those of the hemimorphic zinc-silicate, two crystals being united so as to be symmetrical to the basal plane.

If described as a hemitropy the twins must be geometrically defined as due to twinning about either the macropinakoid 010 or the brachypinakoid 100 with composition parallel to the basal plane; they are analogous to the twins of pyrargyrite described in vol. viii. p. 79 as due to twinning about the prism $10\bar{1} = \infty P2$ with composition parallel to the basal plane.

The two individuals are usually united by their Γ ends (ends at which the form Γ occurs), but sometimes the Γ faces are at the ends opposite to those by which the prisms are united; in this respect also they are analogous to pyrargyrite.

It is another peculiar feature of the crystals that, as is shown in the figure, this mode of twinning is generally combined with the almost universal twin-structure of stephanite which results from hemitropy about the planes $o = 110$.

A prism may, therefore, in addition to the hemimorphic twinning, consist of two or more individuals twinned about faces of the form 110, or may be traversed by twin laminæ parallel to those faces.

Upon some crystals, which appear at first sight holosymmetrical, the prism faces show striations at both ends without any signs of twinning; but on closer examination they prove to be totally distinct; those at one end are the striæ described above, which are inclined to the prism edge at the angle 23° 21½′, are formed by the faces $\Gamma = 731 = 7\breve{P}\frac{7}{3}$, and belong to the zone $[\bar{1}14]$ containing the form $e = 401 = 4\breve{P}\infty$; while those at the other end are inclined to the prism edge at the angle 40° 46′, are formed by the faces $\rho = 421 = 4\breve{P}2$, and belong to the zone $[\bar{1}12]$ containing the form $d = 201 = 2\breve{P}\infty$.

The latter striation is mentioned by Vrba as common on stephanite from Andreasberg.

When a twin crystal has Γ at its outer ends, the striæ and the re-entrant angles which indicate the line of junction are formed, not by Γ, but by the faces ρ, d, and belong to the latter series.

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The two ends of a stephanite prism are therefore to be distinguished; one is characterised by Γ and by striations belonging to the zone $[\bar{1}14]$, the other by ρ and by striations belonging to the zone $[\bar{1}12]$; the direction of these striations, when they are visible, will always show to which end any part of a crystal is to be referred.

My attention was first attracted by the above peculiarities in crystals from Wheal Boys, Endellion, but I have subsequently observed the same indications of hemimorphism in Stephanite from Freiberg, Andreasberg, Gersdorf, Guanaxuato, and Chañarcillo.

(b). The Crystalline form of Kaolinite.

The length of the vertical axis of this mineral given in vol. viii. p. 25 is not correct.

If deduced from the measurements (p. 24) of the crystal represented in Fig. 34, Plate iii., the crystallographic elements are—

$$\beta = 83° 11'$$
$$a : b : c = 0{\cdot}5748 : 1 : 1{\cdot}5997,$$

the angles being

	Measured.	Calculated.
$b\ m$	60° 17′	
$c\ m$	84° 5′	
$c\ n$	78° 8′	
$b\ n$	60° 44′	60° 8½′.

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On Zinc Oxide from a Blast-furnace.

By J. Tudor Cundall, B.Sc., F.C.S.,

Lecturer and Demonstrator of Chemistry in University College, Cardiff.
With a Crystallographic Examination of the same by

A. Hutchinson, B.A.,

Scholar of Christ's College, Cambridge.

[Read November 5th, 1889.]

A CRYSTALLISED substance from a blast-furnace at Mostyn, in N. Wales, having been brought under my notice by Mr. Heywood, of St. Mellons, it was thought worth while to subject it to a careful examination. The largest of the crystals was about 6 mm. long and 2 mm. in diameter. They were translucent, varying in colour from almost colourless to honey-yellow, and were arranged in tufts on what seemed to be altered firebrick. They yielded a pale yellow powder of which the specific gravity was found to be 5·605.

Two different portions were analysed, with the following results :—

		I.	II.
ZnO	...	97·96	98·79
Pb	...	1·02	0·95
S	...	·39	·10
SiO_2	...	·61	trace
FeO	...	·39	trace
		100·37	99·84

In both cases the powder was soluble in dilute hydrochloric acid, with the exception of some glittering grains of lead sulphide.

In I., however, excess of sulphur was present as sulphide decomposed by acids, but in II. the lead was in excess, and present in the metallic state in minute globules. The silica and iron were probably derived from imperfect separation from the matrix.

This substance, then, consists of almost pure zinc oxide, and is deposited in cavities in the wall of the furnace at about its widest part.

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(The furnace was used for the preparation of "spiegeleisen" from an ore containing a considerable quantity of zinc.)

The zinc is apparently volatilised as such, and diffuses into these cavities, where in some cases it becomes oxidised, but in others, when access of oxygen is denied, metallic zinc is deposited.

Crystallographic Examination.—The crystals of zinc oxide sent me by Mr. Cundall as suitable for measurement are small, being about 3 mm. long and from 1-2 mm. in diameter.

They belong to the rhombohedral system, and some few of them are simple doubly-terminated hexagonal pyramids $\{51\bar{3}\}$; the greater number, however, exhibit the following combination of forms :— a $\{10\bar{1}\}$, o $\{111\}$, f $\{2117, 13\}$, k $\{531\}$, m $\{210\}$, x $\{31\bar{1}\}$, and y $\{51\bar{3}\}$. Owing to the development of the crystals in tufts, no doubly-terminated specimen of this habit was to be found, and hemimorphism could not therefore be detected. On one crystal the rhombohedron r $\{100\}$ occurred in combination with a $\{10\bar{1}\}$, o $\{111\}$, and y $\{51\bar{3}\}$. The angle $o\,r$ was not, however, capable of very accurate measurement, and the element 111:100 was therefore calculated from the very good readings = 31°·40′ obtained for the angle ok; the resulting value of 111:100 is 58°·2′, while ox = 61°·37′ and xx' = 52°·12′. These crystals possess a fair cleavage parallel to the base o $\{111\}$, and a perfect one parallel to the faces of the prism a $\{10\bar{1}\}$. They are interesting as exhibiting the new faces r $\{100\}$ and f $\{21\ 17\ 13\}$, and for being much richer in forms than others hitherto described.

The somewhat high indices $\{21, 17, 13\}$ are not to be regarded as certain, for although they agree best with the observed value of the angle $o\,f$=12° 14′ (calculated=12° 17′) the faces of this form are rounded and give indefinite reflections; the simpler indices $\{543\}$ require $o\,f$=13° 1′.

Crystals similar to these have often been observed as furnace products, and in addition to the forms a o r f k m x and y, the following have from time to time been described: b $\{2\bar{1}\bar{1}\}$, l $\{951\}$, w $\{73\bar{1}\}$, d $\{11,3,3\}$, e $\{11,\bar{2},\bar{2}\}$, s $\{911\}$, and its dirhombohedral form σ $\{\bar{8}75\}$.

I append a list of the observed angles, comparing them with those calculated from the element 58° 2′, together with a resumé of the literature.

Angle.	Calculated.	Measured.	
	° ′	° ′	
$o\,r$	58 2	58 10	
$o\,d$	37 1		
$o\,e$	71 25½	71 26	(Koch)
$o\,f$	12 17	12 14	
$o\,k$	—	*31 40	

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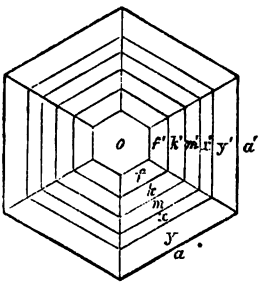
Angle.	Calculated.	Measured.	
	° ′	° ′	
$o\,l$	36 31	36 58	(V. Rath)
$o\,m$	42 47	42 36	
$o\,w$	50 59	50 0	(Koch)
$o\,x$	61 37	61 37	
$o\,y$	74 53	74 50	
$o\,s$	58 30		
$s\,a$	36 19		
$s\,s'$	18 34	18 45	(V. Rath)
$s\,\sigma$	32 24	32 25	(,,)
$d\,a$	58 34	58 30	(Des Cloizeaux)
$d\,d'$	62 52	63 30	(,,)
$x\,x'$	52 12	51 48	
$z\,z'$	57 44	57 45	



The forms $o\,e\,w\,a$ were observed by Koch (*Beitr. z. Kenntniss Kryst. Hüttenprod. Göttingen*, 1822); see also Hausmann (*Handb. d. Mineralogie*, 1847, II. 198). Schabus (*Wien. Ak. Ber.*, 11, 8) and Lévy (*Ann. d. Mines* [4] 4, 516) both observed the combination $a\,o\,x$; the former takes for his element $xx' = 52° 17\frac{1}{2}'$, while Lévy selects $o\,x = 62° 20'$, whence $x\,x' = 52° 34'$.

The same combination has more recently been observed by Rinne (*N. Jahrb. f. Min.* 1888, II. 164-171): he finds $o\,x = 61° 54'$, whence $x\,x^1 = 52° 21'$, his crystals are moreover hemimorphic, as shown both by their development and their etched figures.

Vom Rath (*Pogg. Ann.* 1864, 122, 406; 1872, 144, 580) has described the combination $s\,\sigma\,o\,a$ and a twin exhibiting the forms $a\,b\,o\,l\,x$; he adopts as his element $o\,x = 62° 1'$, and finds that the crystal is twinned about a face of the hexagonal pyramid which makes an angle of 59° 8, with $o\{111\}$, hence it has the indices $\{25,9,7\}$, and taking $ox = 61° 37'$ this angle becomes 58° 42′ : the plane of combination is perpendicular to the twin plane.

The rhombohedron $d\{11,3,3\}$ was found by Des Cloizeaux (*Ann. d. Mines* [4] 1,488) on some crystals formed in cavities in roasted blende; see also Brooke and Miller (*Mineralogy*, 1852, 218).

A large series of crystals from various furnaces have recently been investigated by Greim (*Ber. d. Oberhess. Ges. f. Nat. u. Heilk*, 1886, 24, 29), who described for the first time the forms k, m and y, all of which are present on the crystals I have examined; our values for the angle $o\,k$

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are identical; the form $w\{915\}$, described by Greim as new ($o\,w = 50°59'$), is probably the same as that already observed by Koch ($o\,w = 50°$).

Firket (*Ann. Soc. Géol., Belg.*, 1885, 12 Bull. 191) and Gorgeu (*Bull. Soc. Min. France*, 1887, 10, 36) have also observed the artificial formation of zinc oxide crystals.

The above measurements were made in the Cambridge Mineralogical Laboratory, and my best thanks are due to Prof. Lewis for much kind assistance and advice, and to Mr. Solly for the loan of his Fuess goniometer.

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On Zinc Sulphide replacing Stibnite and Orpiment; Analyses of Stephanite and Polybasite.

By G. T. Prior, M.A.
Assistant in the Mineral Department, British Museum.

[Read January 14th, 1890.]

(*a*) Zinc Sulphide replacing Stibnite.

In a paper in *Zts. f. Kryst.* IX. 186, Professor Laspeyres states that the yellow encrustation upon Felsöbanya stibnite is not cervantite, but a sulphide of zinc, which he determines to be wurtzite, chiefly on the optical ground that a black interference cross was observed between crossed nicols, for the chemical proof based on the solubility in cold concentrated hydrochloric acid can hardly be regarded as very conclusive, considering the fact that he had no true wurtzite with which to make the comparison, but only so-called schalenblende, spiauterite, etc. On this account it seemed desirable to test the solubility of wurtzite in HCl, and accordingly a series of experiments as to the comparative solubility of wurtzite, spiauterite, voltzite and different varieties of blende was made by treating small fragments with cold concentrated HCl, (as was done by Professor Laspeyres) in small tubes, in the mouth of which strips of lead acetate paper were inserted. As far as could be judged by these experiments, the order of solubility was as follows:—

The encrustation: very readily attacked and quickly dissolved.

Voltzite from Joachimsthal and from Geroldseck: attacked at once very readily.

Light-brown botryoidal blende from Wolkenstein, Saxony: attacked at once, almost as readily as voltzite.

So-called ribbon blende from Belgium: freely attacked at once.

Ordinary botryoidal blende from Cornwall: slightly attacked after short time.

Spiauterite from Kapnik, Hungary: slightly attacked after short time.

Wurtzite from Oruro, Bolivia: slightly attacked after some time.

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Deep red crystallised blende from Pzribram: scarcely affected at all after standing for several hours.

A qualitative examination of the yellow crust on all the stibnites from Felsöbanya in the Museum collection showed that in all cases it consisted of zinc sulphide very freely soluble in cold concentrated HCl. On one specimen in which the stibnite in radiating groups was associated with a mass of small quartz crystals, the zinc sulphide occurred partly in the usual form as an encrustation on the crystals and partly as an earthy mass of a dull yellowish colour at the root of the crystal. This mass, very different in appearance from the ordinary honey-yellow encrustation, was so thick that ·3901 gramme could be removed for analysis. It was found to contain—

Zn = 59·22 p.c.
S = 27·85
Sb = 2·2

which, assuming that the antimony occurred as oxide, gives for the atomic proportion of zinc to sulphur—

Zn	:	S
·911	:	·870
or 1·05	:	1

The excess of Zn over S may be due to the presence of oxide, but the difference is perhaps hardly sufficient to support the idea suggested by the above table of solubility, that the encrustation is more closely related to voltzite than to wurtzite.

The specific gravity of the mass was 3·44 at 18° C.

In order to discover whether this peculiar encrustation was restricted to stibnite from Felsöbanya, an examination of the deposit on stibnite from other localities in the Museum collection was made, with the result that two new localities may now be added, viz. Estremadura, Spain, and Siegen, Prussia. On all other specimens the encrustation was found to consist of one or more of the oxides of antimony.

The Siegen specimen, which had been described as "antimonglanz passing into valentinite," was remarkable for the thickness of the deposit, which did not, as in Felsöbanya specimens, form a thin coating, but wholly replaced the terminations of the stibnite crystals, which occurred in small radiating groups on brown spar.

A precisely similar encrustation of zinc sulphide was subsequently found coating and partly replacing botryoidal orpiment on a specimen from Felsöbanya.

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(*b*) Stephanite.

(1) *From Copiapo, Chili.*

The specimen, in size about 5 cm. × 3 cm., without matrix, consists of a group of large stout prisms, with individuals about 15 mm. in length and 20 mm. broad. It was chosen for analysis from its appearance of purity; for, unlike most of the stephanites examined, no pyrargyrite could be detected on it, and when broken into small particles and examined under the microscope by strong transmitted light, the only impurity found consisted of one or two deep red scales of polybasite. The traces of Cu and As found in analysis were no doubt due to this intermixed polybasite. The mineral was decomposed in chlorine, and analysis conducted by methods given in *Min. Mag.* VII. p. 128.

Result of analysis:—

Ag	= 68·65
Sb	= 15·22
S	= 16·02
Cu	trace
As	trace
	99·89

S.G. = 6·26 at 16°C. Weight used in analysis—

For Ag and Sb ... 1·0418 grms.
For S ... ... ·5393 ,,

The atomic proportions are—

	Ag	=	·636
	Sb	=	·127
	S	=	·500

or approximately	Ag	Sb	S
	5	1	4

which corresponds to the formula now generally adopted for stephanite, 5 Ag_2 S. Sb_2 S_3, and not 6 Ag_2 S. Sb_2 S_3, as taken by Rose and still given in some text-books.

The following forms have been observed on the specimen by Mr. H. A. Miers:—

c	001	OP
d	201	2P∞
k	101	P̆∞
f	313	P̆3
P	111	P

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(2) *From Wheal Boys, Cornwall.*

Only two Cornish specimens of stephanite have hitherto been described, viz. one from Wheal Ludcott by Mr. Davies (*Geol. Mag.* 3, 432), and a large crystal from Wheal Newton by Prof. Lewis (*Zeit. f. Kryst.* VII. p. 575). The present specimen consists of bright prisms attaining a length of 13 mm., on quartz which, in parts is coated with minutely crystalline mispickel.

It was thought that an analysis of the specimen might be of interest, since none had hitherto been made on Cornish stephanite.

Unfortunately for the analysis, the crystals of stephanite were found to be interpenetrated in an extraordinary way with pyrargyrite.

To ordinary observation, even with the aid of a lens, the mineral appeared to be pure, and it was only when examining it in strong sunlight that the red light transmitted through small particles of pyrargyrite could be detected on every freshly-exposed surface.

For the specific gravity determination the mineral was broken into small particles and all visible pyrargyrite separated. This specific gravity cannot altogether represent that of the analysed material, since in the subsequent crushing more pyrargyrite was removed. Each of the small particles was separately flattened out under the pestle, and the intimate nature of the mechanical mixture of the two minerals may be judged by the fact, that when treated in this way few particles were found which did not show thin streaks of red pyrargyrite running through the main mass of the stephanite. The particles containing no pyrargyrite would not have been sufficient for analysis, and so a rough separation of the two minerals had to be made as well as possible on the flattened-out particles. This separation could naturally not be perfect, and accordingly the analysis indicates the presence of pyrargyrite by the low p.c. of Ag and high p.c. of Sb., as compared with analysis (1). Making allowance, however, for this slight admixture with pyrargyrite, the analysis shows that stephanite from Cornwall and stephanite from Copiapo are identical in composition.

Result of analysis :—

Ag	= 68·21
Sb	= 15·86
S	= 15·95
Fe	trace
	100·02

S.G. = 6·24 at 17°C.

Weight used for Ag and Sb = ·9704 grms.

for S ·5032 ,,

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The following remarks on the crystalline form of the two Cornish specimens from Wheal Ludcott and Wheal Boys have been contributed by Mr. H. A. Miers:—"The crystals from Wheal Ludcott on the specimen described by Mr. Davies in 1866 are small bright prisms exhibiting a combination of the forms—

c	001	OP
o	110	∞P
m	113	$\frac{1}{3}$P
h	112	$\frac{1}{2}$P
P	111	P
t	203	$\frac{2}{3}\breve{P}\infty$
k	101	$\breve{P}\infty$
d	201	$2\breve{P}\infty$

and are compound crystals twinned both upon the planes 110 and 310.

The crystals from Wheal Boys are large bright prisms attaining a length of 13 mm. and exhibiting a combination of the forms—

c	001	OP
P	111	P
β	011	$\bar{P}\infty$
h	112	$\frac{1}{2}$P
o	110	∞P
λ	130	$\infty\bar{P}3$
a	100	$\infty P\infty$
Γ	781	$7\breve{P}_3^7$
d	201	$2\breve{P}\infty$

They are also twinned both upon the planes 110 and 310 and further show the hemimorphic character and twin structure described in *Min. Mag.* Vol. IX. p. 2.

The hemimorphism and the twinning with parallel axes are betrayed by the faces of Γ which occur only on the inner ends of the individuals and lead to unsymmetrical striations on the bright faces of *o*."

(*c*.) Polybasite.

From Santa Lucia Mine, Guanaxuato, Mexico.

This specimen consists of a group without matrix, of polysynthetic hexagonal tables about 20 mm. in length and 6 to 10 mm. in thickness. The material was very carefully examined for impurities and enclosed minerals. As before, each particle was separately flattened out under the pestle, but no pyrargyrite or argentite was detected in this way. Whether a little stephanite was mixed with the polybasite it would be impossible to

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say. The result of this analysis as well as of many of those hitherto published would seem to imply that such may be the case, but owing to the similarity in appearance of the two minerals such a mixture as occurred for instance, in the case of the Cornish stephanite could not be optically detected. In breaking up the crystals slight differences in lustre in different parts were noticed, but otherwise the material appeared to be quite homogeneous, and no mineral which could account for the copper in any other way than as a normal constituent of the polybasite could be discovered.

The only impurity found, consisted of one or two very small particles with bright yellow metallic lustre, which were easily detected and removed owing to their perfect malleability, which caused them to be flattened out under the pestle in the process of crushing the material for analysis. There was very little of this impurity to deal with, little over a milligram, but a chemical examination with the help of the microscope showed, without doubt, that it consisted of an electrum or gold containing a large proportion of silver. Heated to redness in a small glass tube over the Bunsen flame, it suffered no change whatever, but it fused to a bright yellow malleable metallic globule when exposed for some time to the blowpipe-flame in a small porcelain crucible. Repeated evaporations on a watch-glass with nitric acid appeared to have very little effect upon it. It was only by heating in aqua-regia that it lost its metallic appearance, but did not dissolve readily owing to the layer of silver chloride (found to be soluble in ammonia), which protected the metal beneath: however, by rubbing with the rounded end of a glass rod and exposing the fresh surface beneath, sufficient gold was dissolved to give the purple of Cassius very distinctly. A comparative test made upon a pale specimen of electrum rich in silver showed that it behaved in a precisely similar way with respect to acids.

In the analysis the chlorides of silver and copper left after the decomposition of the mineral in chlorine were reduced in hydrogen, and the resulting metals dissolved in nitric acid. The silver was estimated as chloride and the copper as cuprous sulphide. The arsenic was separated from the antimony by Classen's method.

Result of analysis :—

Ag	= 68·39
Cu	= 5·13
Sb	= 10·64
As	= 0·50
S	= 15·43
	100·09

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Specific gravity = 6·33 at 15° C.

Weight used in analysis :—

For Ag, &c.	1·0760
S	·5013

The atomic proportions deduced from the analysis are :—

Ag	= ·634
Cu	= ·081
Sb	= ·089
As	= ·006
S	= ·481

or approximately

Ag, Cu	Sb. As.	S.
7½	1	5

If Rose's formula $9Ag_2S.Sb_2S_3$ be considered the correct one for polybasite, the above result, like many of those hitherto published, would imply that the specimens contained intermixed stephanite. This idea is supported by the fact that in the analysis of Rose, which approximates most nearly to the formula $9Ag_2S.Sb_2S_3$, there is practically no antimony, so that in this case no stephanite could have been present. It would be interesting to learn, if it were possible, in what respects that particular specimen differed from ordinary polybasite, since it might be almost regarded as another species as distinct from polybasite as proustite is from pyrargyrite.

The specific gravity determinations were made with a 3cc. pyknometer provided with a thermometer-stopper and graduated side tube as described in Graham-Otto's text-book.

Results obtained with this little instrument are surprisingly constant. With stopper very slightly greased, when exactly the same course of procedure is pursued in every detail and in the same order, the difference in two weighings seldom exceeds 0·3 mg., if the temperature is kept constant.

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The Meteoric Iron of Tucson.

By L. Fletcher, M.A., F.R.S. (General Secretary),
Keeper of Minerals in the British Museum.

[Read March 18th, 1890.]

1. TWO large masses of meteoric iron, which have been removed from Tucson, are now preserved, the one at Washington, the other at San Francisco. According to Lippincott's Gazetteer, Tucson is "a post-town, capital of Pima County, Arizona, U.S.A., on the Rio Santa Cruz, and on the Southern Pacific Railroad, about 250 miles east of Yuma. It was founded in the year 1560 by the Jesuits. It contains a church, the Institute of St. Joseph, two free schools, a bank, a newspaper office, a court-house, a United States depository, many stores, and two flour mills. The population in 1880 was 7,007."

Le Conte.

2. Attention was called to the iron of Tucson by Dr. John L. Le Conte of Philadelphia, a distinguished entomologist, in an oral statement made by him at a meeting of the American Association for the Advancement of Science, held at Albany in August 1851. Two accounts of this statement have been published. According to the first and brief official account,[1] Dr. Le Conte, "while passing through the village of Tucson in the preceding February, had observed two large pieces of meteoric iron in use by the blacksmiths of the town as anvils." They were irregular in form; and although imbedded in the ground to make them steady for use, they were about three feet high. Notwithstanding the offer of a high price, "he was unable to get any bits broken from the anvils, but was guided to a cañon between two mountain-ridges in the immediate vicinity, from which both pieces had been taken, where the masses of the meteorites were so abundant as to have given name to the cañon."

In the second and more detailed report[2] of his statement no mention at

[1] *Proc. Amer. Assoc. for Adv. of Sci.*, p. 188.
[2] *Amer. Jour. Sci.*, 1852, ser. 2, vol. 13, p. 269.

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all is made of a visit to the cañon, and it is implied that no such visit took place: it is there stated that the pieces "were brought from a valley in a small mountain-chain about forty miles south-east of Tucsan (*sic*), east of the road leading to Tuvaca (*sic*). In this valley, fragments similar to those seen and of various sizes *were said to be* abundant. From the occurrence of this metal, the valley was called *Canada de Hierro* or *Iron Valley*. Silver mines of great richness are very numerous in that vicinity: the metal occurs as sulphuret, with galena and blende, and also in the native form."

3. Did Le Conte really visit the original site of the iron, or is he merely recording hearsay statements? By the following considerations we are led to infer that his oral statement was initially mis-reported, and that no visit was made by him to the *Iron Valley*.

Le Conte was informally attached to Major Emory's party,[1] which was engaged in the survey of the western part of the boundary between the United States and Mexico, and he spent eighteen months in California. Seeing that he was "passing through" Tucson in February 1851, and that he attended the meeting at Albany in August of the same year, it seems certain that his information about the iron was got during his journey home from California.[2] His stay at Tucson would thus probably last only a few hours; and if it had been otherwise he would have been able, by continued appeal, to overcome the indolence of the blacksmiths, and to get the fragments he desired. It is extremely improbable that an entomologist would have turned aside from his route many miles merely to see the masses *in situ*: he must have had less curious companions who would have objected to the delay: while a journey without an escort as defence from the Indians was then extremely dangerous. And if he had ventured so far out of the track he would not have returned without securing an illustrative specimen, and would have given a description of the mode of occurrence and the distribution through the valley. As a matter of fact his reference to the Tucson iron was only a casual one, made after hearing Professor Shepard read a paper relative to a meteoric stone which had fallen at Deal in New Jersey more than twenty years before.

We may thus conclude that the later was the more correct version of Le Conte's original statement, and that he was merely recording information given to him at Tucson.

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[1] *Smithsonian Report for* 1851, p. 53.

[2] *Amer. Jour. Sci.*, 1854, ser. 2, vol. 18, p. 369.

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Bartlett.

4. A year later, in July 1852, the two large masses were seen at Tucson by John Russell Bartlett,[1] then the United States Commissioner for the delimitation of the United States and Mexican frontier.

One, a ring-shaped mass, of which he gives a figure, was in use as an anvil in the blacksmith's shop. He writes as follows :—"It was found about 20 miles distant towards Tubac, and about 8 miles from the road, where we were told are many larger masses. There is another mass within the garrison grounds, of which I did not take a sketch. With much labour Dr. Webb broke off a fragment of this meteorite for the purpose of analysis."

Parke and Shepard.

5. In November 1854,[2] Professor Shepard gave a description of some small fragments, the largest not more than a quarter of an ounce in weight, which had been sent by Lieutenant John G. Parke, of the United States Topographical Engineers, on his return from Sonora. Parke had just been engaged in the survey for a railroad across the continent, and had chipped off the fragments while at Tucson in February 1854 : he was told that there were three masses, though only the two larger ones were seen by him. According to information supplied by Parke "they were found in a cañada of the Santa Rita Mountain, about 25 or 30 miles to the south of Tucson. Two of them were shown to us by the Commandante, both being used as anvils. One lies within the *presidio*, and is of a very peculiar form, being annular and somewhat like a seal-ring of huge proportions. Its exterior diameter is about 8½ feet: its interior about 2 feet. It weighs nearly 1,200 lbs. The other piece is in front of the Alcalde's house. It weighs about 1,000 lbs. and has an elongated prismatic form, serving well the purposes of an anvil. It is partially buried in the soil, but has two feet of its length projecting above the ground. The Alcalde and Commandante would not consent to our removing the masses, even if we had had the means."

The position of the Sierra de la Santa Rita is shown in the map[3] ac-

[1] Personal Narrative of Explorations and Incidents in Texas, New Mexico, California, Sonora and Chihuahua. New York, 1854, vol. 2, p. 297.

[2] *Amer. Jour. Sci.*, 1854, ser. 2, vol. 18, p. 369. Reports of Explorations and Surveys for a railroad from the Mississippi River to the Pacific Ocean: (Senate Documents): 1855, vol. 2, containing *inter alia* a report by J. G. Parke on Explorations between Doña Ana and Pimas Villages, p. 7.

[3] Reports of Explorations, &c. 1861; vol. 11.

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companying the report of the survey made by Parke; it is on the eastern side of the road, and north of Tubac.

Lawrence Smith.

6. Others of the fragments were sent by Parke to Professor Lawrence Smith,[1] and were analysed by him. The historical particulars given by Smith are quoted from information sent to him by Bartlett, and are identical with those published shortly afterwards in Bartlett's work.

Genth.

7. In April 1855[2] Dr. F. A. Genth, of Philadelphia, gave the results of analysis of some pieces of a specimen of the Tucson iron: the specimen had been presented to the collection of the Academy of Natural Sciences of Philadelphia by Dr. Heermann. Though Dr. Genth gave no history of the specimen, there can be no doubt that it was one of the fragments referred to by Parke, for Dr. A. L. Heermann[3] was the naturalist attached to that section of the Survey of the Pacific Railroad Route, on which Parke was engaged, and both were at Tucson together.

Michler.

8. The Tucson iron was seen by Lieutenant Michler[4] during a visit made in June 1855: he merely states that "a fine specimen of meteoric iron brought from the Santa Rica is to be seen at Tucson, and is used as a blacksmith's anvil. It is massive and quite malleable." Michler, who also belonged to the United States Topographical Engineers, was in charge of a surveying party under Emory, the successor of Bartlett, in connection with the United States and Mexican boundary: his party was encamped close to Tucson for nearly a month, and during that time received every attention and civility from Captain Garcia, who commanded the place. According to Michler, Tucson was then "inhabited by a few Mexican troops and their families, together with some tame Apache Indians. It is very prettily situated in a fine fertile valley at the base of the Sierra de Santa Catarina." From Tucson Michler went on to Los Nogales, sixty-nine miles to the south of it: "the road lay in the valley of

[1] *Amer. Jour. Sci.*, 1855, ser. 2, vol. 19, p. 161. (The greater part was read before the Amer. Assoc. Adv. of Sci. in April 1854.)

[2] *Proc. Ac. Nat. Sc. Phil.*, 1856, vol. 7, p. 317.

[3] *Ibid.*, p. 129; *Smithsonian Report for* 1854, p. 84.

[4] *Rep. of the U.S. and Mex. Bound. Sur.* (W. H. Emory), 1857, vol. 1, part 1, p. 118.

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the Santa Cruz as far as the Rancho de las Calabazas between high mountains. On the east are the Santa Catarina, with its top covered with lofty pines, and the Santa Rita rich in minerals: and on the west are the Sierra Rica and the Sierra Atacosa." Calabazas is shown on the maps as on the side of Tubac more remote from Tucson: the distance by road from Tucson to Tubac is 48½ miles, from Tubac to Calabazas 18 miles.

Comparison of the above statements.

9. Owing to the surveys of the Mexican boundary and Pacific Railroad Route, the masses of iron at Tucson were thus seen and noticed within the short space of the four years, 1851-55, by Le Conte, Bartlett, Parke and Michler, but the original site was visited by none of them: their information as to its position is hearsay, and was doubtless communicated in turn to each of them, either by the Mexican Commandante or the Tucson blacksmiths: their statements are in all probability merely different versions of a single original. According to their various accounts the site is about 40 miles south-east of Tucson, and east of the road leading to Tuvaca (Le Conte): about 20 miles distant towards Tubac and about 8 miles from the road (Bartlett): about 25 to 30 miles south of Tucson in the Santa Rita Mountain (Parke): in the Santa Rica (Michler).

10. (1) All these statements agree in placing the site to the south of Tucson: (2) the three which specify the distance agree tolerably well with each other: (3) as according to Michler the Santa Rita is east of the road leading to Tubac, the only two which specify the side of the road agree in making it east (Le Conte and Parke): (4) the only disagreement is thus presented by Michler's statement that the iron was brought from the Santa Rica, for Sierra Rica is said by him to be on the west of this road. It will be conceded, however, that Rica is here a misprint for Rita: the two words appear close together in Michler's report, rendering such a misprint easy; this view is confirmed by the remark that Michler in the preceding sentence mentions, not Santa Rica, but Sierra Rica and Santa Rita: indeed the association of the words Santa and Rica (Holiness and Riches) is an unlikely one, while that of Santa and Rita is not uncommon. Further we may add that Michler speaks of Santa Rita as being rich in minerals, which accords with the character given to the locality of the cañon in the second version of Le Conte's statement.

11. We infer that in the years 1851-5 it was stated by the Mexican Commander of the fort at Tucson that the masses had been brought from a cañon in the Santa Rita, that the cañon was reached by travelling along the road from Tucson towards Tubac for a distance of 20 or 30 miles, and

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by then turning off in an easterly direction for about 8 miles: further, that the district was rich in silver minerals.

Irwin and Ainsa.

12. When the survey was concluded (1856) the boundary between the United States and Mexico was transferred about seventy miles to the south of Tucson, and the town passed into the possession of the United States. Soon afterwards, in 1857, Dr. B. J. D. Irwin, Surgeon in the United States Army, who was stationed at Fort Buchanan, south of Tucson, found the annular mass in one of the by-streets half buried in the earth; and, no person claiming it, he publicly announced that he took (nominal) possession of it with the intention of forwarding it to the Smithsonian Institution. In 1860 the mass was sent, by the agency of Mr. Agustin Ainsa as far as Hermosillo, and later to Guaymas, a port of Sonora in the Gulf of California: in 1863 it was taken to San Francisco by Jesus M. Ainsa, and thence by Santiago Ainsa to the Smithsonian Institution at Washington by way of the Isthmus of Panama.

In a letter dated Sept. 5, 1863, sent to Mr. Henry, the Secretary of the Smithsonian Institution, Dr. Irwin[1] says:—"The only history I can give you is a vague one, as there is no written record of its advent in Tucson. The old inhabitants of that place all agree that it was brought thence from the Santa Catarina mountains, which lie to the north of Tucson, about midway between the Rio San Pedro and that town. It was brought in by the military stationed at the old *presidio*, where it remained until after the withdrawal of the Spanish garrison. It was then taken into town, set up on end, and used as a kind of public anvil for the use of the inhabitants. The smaller one was used in a blacksmith's forge for similar purposes." "The people of Tucson all agree that a shower of these meteorites fell in the Santa Catarina mountains some two hundred years ago, and I have been told that there were plenty of them remaining in the mountains. I never was in the immediate portion of the mountain-range where they report the specimens are to be found, so I cannot vouch for the correctness of their reports."

13. In another letter, dated August 26, 1863, sent likewise to Mr. Henry in response to an inquiry for information, Mr. Santiago Ainsa makes the following statements[2]:—"The history of this aerolite we have from our grandmother, Doña Ana Anza de Islas, daughter of Don Juan Bautista Anza, our great-grandfather. The Jesuit missionaries had the

[1] *Smithsonian Report for* 1863, p. 85. [2] *Ibid.*, p. 86.

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earliest knowledge of this curiosity. There were various theories entertained about it; but it was generally believed to proceed from some iron-mine in the vicinity, which belief holds to this day in Sonora. In an expedition made by Don Juan Bautista Anza, then 'Gran Capitan de las Provincias del Occidente,' about the year 1735, to the country about Tucson, he was induced to visit the aerolite, and he undertook the work of transporting it to Spain. The place where it was found is called *Sierra de la Madera*, on a spot called *Los Muchadios*. Through the want of proper means and the bad state of the roads (having to carry it to San Blas, then the nearest port of entry) the work of transportation was given up, and they were satisfied to take it as far as Tucson."

14. In another part of the same Report[1] the name of the place is given by the Secretary, on the basis of Mr. Ainsa's letter, as *Los Muchaches*, in the *Sierra Madre*. As both statements are founded on the same letter, one or other or both of the words *Muchaches* and *Muchadios* must be the result of an error of printing, and inspection of the written words makes it clear that the variation could very easily arise in such a way: as *Muchadios* is not given in the Spanish dictionary, and *Muchachos* is the ordinary Spanish word for "boys," and as the names of Mexican localities have generally a simple Spanish interpretation, it is most satisfactory to regard both as misprints, and to take the *ch* of one version and the *os* of the other, thus adopting *Los Muchachos* as the correct spelling. On the other hand *Sierra Madre* is probably a misinterpretation of *Sierra de la Madera*: it is clearly not a mere misprint. Sierra Madre (or Mother Range) is the name given to one of the principal mountain-ranges, extending for hundreds of miles through Mexico and the United States: and in his interpretation of the Ainsa letter, Mr. Henry would appear to have taken the unknown name *Sierra de la Madera* to be merely another mode of writing *Sierra Madre*. Such a term would be too wide in its signification to have had any utility in the indication of a locality. But there is a common Spanish word *Madera* meaning *timber*: so that *Sierra de la Madera* might be a name given to any well-timbered mountain-range. That such a name would, up to 1855 at least, be peculiarly appropriate to the range on the east of the road leading from Tucson to Tubac is evident from the description given by Michler:—"On the east are the Santa Catarina, with its top covered with lofty pines, and the Santa Rita rich in minerals." In 1777, according to the Tucson archives,[2] there was an abundance of excellent pine in the Sierra de Santa Rita itself.

[1] *Ibid.* p. 55.

[2] *Reports of Explorations and Surveys, &c.*, 1857, vol. 7, appendix C.

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15. This view is fully confirmed by a statement read by Professor Whitney[1] at San Francisco on July 20, 1868. He quotes a memorandum furnished by "Mr. James M. Ainsa," which, though identical in its general information with the letter dated August 26, 1868, sent by Mr. Ainsa direct to Mr. Henry, is so far distinct from it as to be an undoubtedly independent document. *Los Muchachos* is not mentioned at all, but the name of the mountain-range appears as *Sierra de la Madera*.

Comparison with the previous statements.

16. *Sierra de la Madera* is not mentioned on any accessible map, and Ainsa himself gives no information as to whether the site is north or south of Tucson. Still his letter would indirectly suggest that the place is to the north of Tucson, since he states that the iron was being transported to the port of San Blas, and therefore southward. Irwin, for his part, directly states that the masses were brought from the north of Tucson.

The only explanation which will bring into harmony these two statements and that which has reached us through Le Conte, Bartlett, Parke and Michler, seems to be the following:—As regards Ainsa's statement: the transportation to San Blas was a matter of difficulty, so much so that it was eventually abandoned; hence the masses may have been found to the south of Tucson, transported to the Tucson and Tubac road, and afterwards along it in the direction opposite to that of San Blas, either when the idea of transport had been finally given up, or when it was decided to wait for better means of carriage; the masses in such case being taken northwards and preserved in the neighbouring *presidio* of Tucson. As for Dr. Irwin, a glance at the wording of his statement makes it probable that he was merely told by the inhabitants of Tucson that the masses had been brought from the Santa Catarina mountains, and that he himself added the information that the mountains are to the north of Tucson, about midway between the Rio San Pedro and that town. In fact the only Sierra de Santa Catarina mentioned in various maps is in the position thus indicated by Irwin. But a reference to Michler's report shows that, at least in 1855, the term Sierra de Santa Catarina was by some persons differently applied: Michler speaks of Tucson as being "very prettily situated in a fine fertile valley at the base of the Sierra de Santa Catarina," and in describing his journey from Tucson to Tubac says that "the road lay in the valley of the Santa Cruz between high mountains. On the east are the Santa Catarina and the Santa Rita."

[1] *Proc. Calif. Ac. Nat. Sc.*, 1863, vol. 3, part 1, p. 48.

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Further, on more than one map the Sierra de Santa Catarina is marked as extending from the north side of Tucson to the south of Tubac.[1] The information given by Irwin is thus not inconsistent with the former statements, if we may assume that he had misapprehended what was intended to be meant by the term "Santa Catarina mountains."

Velasco.

17. The correctness of the above arguments is established by the following paragraph from a work published by Velasco[2] in the year 1850, a date antecedent to that of any of the publications above referred to; as Velasco's work is not easily accessible the paragraph is also given in the original Spanish :—[3]

"Between the presidio of Tucson and Tubac is a mountain-range called Sierra de la Madera and (a pass called) Puerto de Los Muchachos. In it are seen enormous masses of native iron, and many have rolled to the foot of the said sierra. One of the masses of a moderate size was transported to Tucson, and has stood for many years in the *plaza* (square) of the said presidio."

Scarcely a single map gives any information relative to the region adjacent to Tucson and Tubac: but in Stieler's Atlas the southern part of the range on the eastern side of the road between Tucson and Tubac is designated Sierra de la Santa Rita, and a pass running in an easterly direction at the north side of this sierra is marked as Puerto de los Muchachos. The map is based on the observations of Captain A. W. Whipple, of the United States and Mexican Boundary Commission: he travelled through the Puerto de Los Muchachos in 1853, and his route is indicated in Parke's map already referred to.

Whitney.

18. Professor Whitney of San Francisco (who cites an English translation of Velasco's work, published in 1861), summarising the contents of various letters sent to him, said on February 19, 1866[4] :—

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[1] e.g. *Nueva Mapa de Mexico*, 1866. Pub. por Colton & Co., New York, U.S.A.

[2] *Noticias Estadisticas del Estado de Sonora, &c.* By Jose Francisco Velasco. Mexico, 1850, p. 221.

[3] "Entre el presidio del Tucson y Tubac, hay una sierra que llaman de la Madera y puerto de los Muchachos. En ella se ven masas enormes de fierro vírgen, y muchas están rodadas al pié de dicha sierra. De aquellas masas de fierro llevaron una mediana al Tucson, la cual hace muchos años ecsiste tirada en la plaza de dicho presidio."

[4] *Proc. Calif. Ac. Nat. Sc.*, 1866, vol. 3, part 3, p. 241.

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"It is stated by several persons who have visited southern Arizona, among whom Dr. Horn may especially be mentioned, that it is universally believed, and vouched for by apparently trustworthy explorers, that there are many large masses of iron near the summit of the range next east of Tucson."

19. One odd conclusion follows from the above; namely, that Dr. Irwin was actually stationed in the immediate neighbourhood of the true locality: for Fort Buchanan is on the eastern side of the Tucson and Tubac road, and about 30 miles from Tucson: indeed, it appears to be approached from the Tucson and Tubac road through the Puerto de los Muchachos itself. Hence it would seem that he was only prevented from finding any remaining masses by an unlucky misapprehension of the term "Santa Catarina mountains."

Removal of the masses from Tucson.

20. We have already seen that one of the two large masses, the ring-shaped one figured by Bartlett, was removed from Tucson in 1860, and deposited in the hall of the Smithsonian Institution at Washington in 1863. The other was taken possession of by General James H. Carleton, and sent to San Francisco in the year 1862:[1] Carleton was in command of the Column from California; he presented the mass to the City of San Francisco as a memento of the march of his Column, and asked that it might be "placed upon the Plaza, there to remain for the inspection of the people and for examination by the youth of the city for ever." It was, however, deemed advisable to keep the specimen in a safer and drier place, and it is now in the hall of the Pioneer Society.[2] A figure of the mass, prepared from a photograph sent to him by Professor Whitney, has been published by Haidinger[3].

Form and Dimensions.

21. The dimensions of the ring-shaped mass now at Washington are given by Whitney[4] as follows:—

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[1] *Proc. Calif. Ac. Nat. Sc.*, 1863, vol. 3, part 1, p. 33.
[2] *Mineral Resources of the United States for* 1883-4 (Williams), p. 290.
[3] *Sitz. Ak. Wien.*, 1863, vol. 48, part 2, p. 303.
[4] *Proc. Calif. Ac. Nat. Sci.*, 1863, vol. 3, part 1, p. 49.

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"Greatest exterior diameter	49 inches.
Least exterior diameter	38 inches.
Greatest width of central opening	26½ inches.
Least width of central opening	23 inches.
Greatest thickness at right angles to plane of ring... ...	10 inches.
Width of thickest part of the ring	17½ inches.
Width of narrowest part	2¾ inches.
Weight estimated by Ainsa as	1,600 lbs."
An inscription on the specimen now gives the weight as ...	1,400 lbs.

The form of the mass now at San Francisco is described by Whitney as follows:—

"Shape irregular, but in general that of a flattened elongated slab; length, 49 inches; average breadth, 18 inches; thickness varying from 2 to 5 inches. Weight, 632 lbs."

Supposed difference in the characters of the masses.

22. There has been a certain amount of discussion as to whether the two masses are not essentially different in their characters. By a curious coincidence they were both in San Francisco at the same time, and Professor Whitney had the opportunity of directly comparing them. He reports as follows:[1]—

"On examining with a magnifying glass a fractured surface of the ring-shaped iron, it was seen at once to be different in composition from the Carleton meteoric iron, and my conjecture that Professor Smith was mistaken in supposing that he analysed a fragment from the mass figured by Mr. Bartlett was confirmed. It is now almost certain that Messrs. Brush and Smith did analyse fragments of the same mass (the Carleton one)."

23. Though there may still be some doubt as to which mass Professor Smith's fragments were taken from, the doubts which had arisen in the mind of Whitney were the result of a misunderstanding. Smith reproduced the figure of the ring-shaped mass as sketched by Bartlett, who had furnished him with information relative to the iron before the actual publication of the "Personal Narrative": hence Whitney inferred[2] that Smith's analysis was made on the fragments mentioned in Bartlett's work, and those appear to have been got by Dr. Webb from the second mass

[1] *Ibid.*, p. 49.
[2] *Ibid.*, p. 34.

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(the Carleton one) in the garrison grounds, though Bartlett's statement is wanting in precision. But a reference to Smith's paper shows that this was not the case: the fragments were obtained, not from Webb or Bartlett, but from Parke, who in the report sent to Professor Shepard failed to indicate from which mass they had been taken. Lawrence Smith appears to have been under the impression that they were taken from the ring-shaped mass, and it is possible that he may have received direct information from Parke to that effect.

24. Baron von Richthofen, who was in San Francisco at the time that the ring-shaped mass was in the city, also supported the view of Whitney in a letter published by Haidinger:[1]—"Brush calls attention to the striking agreement of his analysis of the Carleton iron with an analysis made by Lawrence Smith of an iron from Tucson. A comparison of the two meteorites leaves however scarcely a doubt that Bartlett knew both, and that both analyses have been made on pieces of the Carleton mass. The ring-shaped mass has so different a mineral composition that we must infer an important difference in the chemical constituents. Schreibersite and olivine are not observable in it, while on the other hand there is a large number of white and apparently crystalline grains which look like a felspar. Whitney and I came to the conviction that they may be anorthite."

25. After examination of the etched faces, Brezina says:—"The Ainsa iron presents a certain similarity with the Carleton iron, yet not sufficient to allow of their being placed together without further investigation."[2]

The masses are products of a single meteor.

26. With regard to this point, the above history of the Tucson iron is sufficient to establish beyond reasonable doubt that both masses have been brought to Tucson from the same valley, and have resulted from a single meteor. It must be remembered that the observations of Whitney and Richthofen were merely preliminary ones, made on rough fractured surfaces of the masses, and that the fragment of the annular mass available for examination by Brezina weighed only 8 grams, and had probably been more or less hammered at Tucson during its removal from the block. In the British Museum there are now good fragments of both masses, one of them sent from San Francisco many years ago through

[1] *Sitz. Wien. Ak.*, 1863, vol. 48, part 2, p. 306.

[2] *Die Meteoriten-sammlung in Wien*, 1885, p. 71.

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Professor Whitney, and the other from Washington more recently through Dr. F. W. Clarke. They have been lately polished, and the identity of their essential characters is now manifest: and this identity is one of characters extremely rare in meteoric irons. Masses of iron, like those of Krasnojarsk and Breitenbach, having numerous disconnected pores filled with stony matter, are not frequent among meteorites; but in the case of both of the Tucson masses not only is this a characteristic feature, but in each of them the grains of included silicate are on a much smaller scale than those included in other irons of the same type. The included grains are crystalline, and are identical in aspect. One of the sections is 75 mm. long, and has a width increasing from zero to 50 mm.; the other is 40 mm. long and has a width varying between 44 and 70 mm. Most of the included grains, thousands in number, are only one or two-tenths of a millimeter in diameter, but there are a few of which the thickness reaches a millimeter: their distribution is generally irregular, but in one part of each section they are arranged in parallel slightly curved lines, and are elongated in the same direction. Irregular fields, sometimes 5 or even 8 mm. in diameter, appear at first sight to be free from enclosures, but the presence of microscopic grains is indicated by the punctuation which becomes visible when the polished face is examined with the aid of a lens. No Widmanstätten figures were formed when the polished faces were etched with bromine-water, but over the whole extent of both sections there became visible an irregular network of yellow metallic lines, resembling tænite or schreibersite, and round each enclosure, large or small, was seen a linear margin of the same material.[1]

As it is impracticable to give a special name to every separate mass of a meteoritic fall, the names of Irwin-Ainsa iron, Ainsa iron, Signet iron, Tucson-Ainsa iron, Carleton iron and Tucson-Carleton iron may therefore be advantageously dropped from scientific literature, and the masses be designated simply as Tucson iron.

27. It is thus of trivial importance whether the fragments sent to Shepard, Genth and Smith, were got from the one or the other mass, for different parts of the same mass may present as great variations of mineral constitution as distinct masses belonging to the same fall: the fragment sent to Brush was taken from the mass now at San Francisco.

Specific Gravity.

28. The specific gravity, according to Shepard, is 6·66: according to Smith 6·52, 6·91, 7·13 for three different fragments; his chemical examination was made on the last, which appeared to be the most compact

[1] See also G. Rose's *Beschreibung der Meteoriten zu Berlin;* 1864, p. 150.

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and free from stony particles: the specific gravity of a fragment, as determined by Brush, was 7·29.

Chemical analyses made by Shepard, Smith, Genth, and Brush.

29. The examinations made by Shepard, Smith, Genth, and Brush, leave some doubt as to the true nature of the stony matter.

1. After the solution of the metallic portion in *aqua regia*, Shepard found a residue consisting partly of a mealy powder and partly of small ovoidal grains, some of them milk-white, some perfectly limpid, others milky on one side and limpid on the other, and therefore all probably belonging to a single mineral species: he was led to regard the mealy powder as of the same nature as the ovoidal grains, and to infer from general resemblance that the silicate was likely to be identical with that of the Bishopville stone to which he had given the name of *chladnite* (but which is now known as enstatite).

2. Smith separated some few particles of the stony matter mechanically, and from its general appearance when seen with a lens, and from the easy solubility in acids when it yielded silica and magnesia, decided that it was undoubtedly *olivine*. Like Shepard he points out that some of the silicate is in a pulverulent condition.

3. Genth reports as follows:—"On evaporation of the solution by nitric acid, and subsequent moistening of the dry mass by hydrochloric acid, all the substances were taken up excepting a small residue of siliceous matter. This partly dissolved on boiling with carbonate of soda, leaving a residue which I took for a felspathic mineral: the quantity obtained, however, was too small for further examination; the small quantities of alkalies, lime and alumina (in the bulk-analysis) speak in favour of this view, and indicate that the residue insoluble in carbonate of soda is *labradorite*, a mineral which is partly decomposed by acids. The silica, soluble in carbonate of soda, results undoubtedly from the decomposition of *olivine*.'

4. Brush, after examination of the residue left behind when the metallic portion had been dissolved out by nitric acid, gave a description of the ovoidal grains which perfectly agrees with that of Shepard, but remarked that their behaviour before the blowpipe very much resembled that of *olivine*. He further reported as follows:—

"For the quantitative examination a fragment weighing 4·3767 grams was treated with *aqua regia*, and after solution of the iron the whole was evaporated; on approaching dryness, gelatinous silica separated, showing that the silicate had been, partially at least, decomposed by the acid.

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After heating until the silica was rendered insoluble, it was repeatedly treated with acid and evaporated, so as to insure the oxidation of all the schreibersite; and finally the soluble part was taken up with hydrochloric acid, and on dilution separated from the silica and insoluble residue. The insoluble residue, containing free silica and undecomposed silicate, was perfectly white and free from all traces of schreibersite. It weighed 0·1855 grm. It was fused with carbonate of soda, and the silica and bases determined in the usual manner. It yielded:—

SiO_2	0·1590
FeO	0·0054
Al_2O_3	minute trace
CaO	0·0028
MgO	0·0168
	0·1840."

Analytical results.

30. It will be convenient to insert here the following complete analytical results of Smith, Brush, and Genth:—

	Smith.	Genth.			Brush.
		I.	II.	III.	
Fe	85·54	83·47	not est.	83·64	81·65
Ni	8·55	9·44	8·69	9·85	9·17
Co	0·61	0·42	0·37		0·44
Cu	0·03	0·008	not est.	not est.	0·08
P	0·12	0·10	not est.	0·15	0·49
Al_2O_3	trace	trace	trace	trace	trace
CaO	...	0·46	0·55	not est.	1·16
MgO	2·04	2·59	2·03	2·15	2·43
Na_2O	...	not est.	not est.	0·174	...
K_2O	...	not est.	not est.	0·098	...
Cr_2O_3	0·21	not est.	not est.	0·50	...
SiO_2	3·02	2·89	not est.	4·17	3·68
Labradorite (?)	...	1·05	not est.		...

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Deductions from the analytical results.

31. Whatever the true nature of the stony matter, the grains included in the iron are obviously very different in size; and unless the action of the acid has been very prolonged the larger grains, whatever their nature, may escape complete decomposition: hence an opinion that the residual silicate is more difficultly decomposed than olivine, based solely on the incomplete decomposition of the stony matter by the acid, must in any case be received with caution.

a. "The general resemblance" and the "presence of decided traces of magnesia in the acid solution," relied upon by Shepard as supporting the view that the stony matter is possibly identical with that of the Bishopville stone, are obviously characters of no great weight.

b. Smith considered the stony matter to be olivine: his experiments undoubtedly prove that the particles, separated by him mechanically, differed from the Bishopville silicate in being easily decomposed by acids: still he only proved the presence of magnesia and silica as constituents, and left it undecided whether more than one kind of stony material is included in the iron.

c. Genth inferred from his experiments that the stony matter consists largely of olivine, but that there is an appreciable proportion of a felspathic material, probably labradorite. The first inference is based on the amount of silica set free through the action of the acid; the second on the presence of material undecomposed by the acid, and on the small quantities of alkalies, lime and alumina found in the acid solution. The presence of labradorite cannot, however, be regarded as established by him: in the first place, no evidence is adduced that the undecomposed material differs from that which has been decomposed; and in the second place, if the alkalies and lime found in the acid solution had been due to labradorite, they would have been accompanied by more than a trace of alumina.

d. In fact, Brush (who was probably unaware of Genth's analysis) came to the conclusion that the undecomposed silicate, obtained in the course of his own examination, was olivine. His analysis of the mixed silica and undecomposed silicate was imperfect in that a separation of the two substances was not made: still the numbers obtained are of value in deciding on the nature of the residue. The constituents are those of

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either olivine or bronzite, and are not those of a felspar. If the substance be an olivine ($2R''O.SiO_2$), the amount of silica combined with the bases will be 0·0188, and the composition will be as follows :—

	Undecomposed Silicate.		Olivine of Fogo I. (Deville).[1]	Olivine of Imilac (von Kobell).[2]	Olivine of Krasnojarsk (Berzelius).[3]
	Determin'd Weights.	Percentage Composition.			
SiO_2 ...	[0·0188]	[42·92]	40·19	40·79	40·86
FeO ...	0·0054	12·33	15·27	12·10	11·72
MnO ...	...	...	2·27	...	0·43
CaO ...	0·0028	6·39	5·12	...	...
MgO ...	0·0168	38·36	35·70	47·05	47·35
Al_2O_3 ...	trace	trace	0·80	0·02	...
	[0·0438]	[100·00]	99·35	99·96	100·36

It must be remembered that according to this calculation the percentage composition of the undecomposed material is based on the analysis of only 0·0438 grams.

The similarity of the numbers thus obtained to those which characterise certain terrestrial and meteoritic olivines will be obvious from the above table.

32. The bulk-analyses made by Smith, Genth and Brush, all indicate that a basic silicate is present : the proportion of the lime and magnesia to the silica is alone sufficient to prove the presence of a silicate more basic than enstatite ; and as the stony matter certainly contains ferrous oxide as well as lime and magnesia, the basicity of the stony matter is considerable. Hence, we may take it that there is absolutely no doubt that the stony matter consists very largely, at least, of olivine ; and that so far there is no valid proof of the presence of any other kind of silicate.

If there is only one kind of silicate (an olivine) present, its composition can be determined from each of the bulk-analyses ; and the results ought to correspond with each other and with that deduced for the undecomposed residue analysed by Brush.

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[1] *Zeitsch. d. deutsch. geol. Gesell.* 1853, vol. 5, p. 693.

[2] *Corresp. Bl. zool. min. Vereines in Regensburg*, 1851, p. 112.

[3] *Pogg. Ann.* 1834, vol. 33, p. 134.

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The following results are obtained by calculation :—

		Smith.	Genth.	Brush.
SiO_2	...	34·87	36·58	35·94
MgO	...	23·56	28·61	24·06
FeO	...	[41·57]	[24·94]	[28·52]
CaO	...	—	6·46	11·48
Na_2O	...	—	2·15	—
K_2O	...	—	1·26	—
		100·00	100·00	100·00

The numbers differ considerably, but are deduced from analyses which are evidently incomplete : in the analysis made by Brush the alkalies were probably not looked for, owing to the insufficiency of the material : the same may be said of Lawrence Smith's analysis, with the addition that the lime, also having escaped notice, has been either lost, or weighed along with the iron or magnesia.

Mineralogical interpretation of the analytical results.

33. It seemed that in the case of analyses made by such experienced chemists as Lawrence Smith, Genth and Brush, it ought to be possible, notwithstanding the differences in their numerical results (§ 30), to find a mineralogical interpretation which will agree with the analyses within the ordinary limits of experimental error : we have to remember that the meteoritic fragments are mixtures of different minerals, and that the proportions of the latter may be more or less variable.

34. The following is offered as a satisfactory solution of this problem : —

(*a.*) The meteorite is a mixture of nickel-iron, olivine, schreibersite and chromite : the composition of the nickel-iron being :—

Iron	...	...	89·89
Nickel	...	...	9·58
Cobalt	...	...	0·49
Copper	...	...	0·04
			100·00

and that of the olivine :—

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		Oxygen.	
FeO	24·07	5·35	
MgO	27·87	10·85	
CaO	8·67	2·48	
Al_2O_3	trace	...	19·44
Na_2O	2·15	0·55	
K_2O	1·26	0·21	
SiO_2	36·48	...	19·44
	100·00		

The schreibersite and chromite, which are relatively small in quantity, may be assumed to have the average composition indicated by the formulæ Fe_2 Ni P (Fe 55·53, Ni 29·09, P 15·38) and $FeO{\cdot}Cr_2O_3$ (FeO 32·11, Cr_2O_3 67·89).

(*b.*) The proportions of the mineral constituents vary throughout the masses: this is obvious to the unassisted eye, and the extent of the variation is shown by the differences of specific gravity: for the fragments analysed by Lawrence Smith and Brush, and the fragment I. analysed most completely by Genth, the proportions were as follows:—

	Smith.	Genth.	Brush.
Nickel-iron ...	90·64	90·03	86·24
Olivine ...	8·29	8·60	10·05
Schreibersite ...	0·77	0·64	3·18
Chromite ...	0·30	0·73	0·53
	100·00	100·00	100·00

35. The agreement of the calculated and observed results is shown in the following tables:—

LAWRENCE SMITH.

	Nickel-iron.	Olivine.	Schreibersite.	Chromite.	Total.	Calculated.	Observed.	Differences.
Fe	81·48	1·55	0·43	0·08	83·54	85·54	85·54	0
O	..	0·44	..	0·02	0·46	0·47	..	..
Ni	8·68	..	0·22	..	8·90	9·11	8·55	—0·56
Co	0·44	..	..	..	0·44	0·45	0·61	+0·16
Cu	0·04	..	..	..	0·04	0·04	0·03	— ·01
P	..	..	0·12	..	0·12	0·12	0·12	0
Cr_2O_3	..	..	..	0·20	0·20	0·21	0·21	0
MgO	..	2·27	..	..	2·27	2·33	2·04	— ·29
CaO	..	0·72	..	..	0·72	0·74	..	..
Na_2O	..	0·18	..	..	0·18	0·19	..	..
K_2O	..	0·10	..	..	0·10	0·10	..	..
SiO_2	..	3·03	..	..	3·03	3·10	3·02	— ·08
Total ..	90·64	8·29	0·77	0·30	100·00	102·40	..	..

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GENTH.

	Nickel-iron.	Olivine.	Schreibersite.	Chromite.	Total.	Calculated.	Observed.	Differences.
Fe	80·93	1·42	0·35	0·18	82·88	83·47	83·47	0
O	..	0·40	..	0·05	0·45	0·45	..	..
Ni	8·62	..	0·19	..	8·81	8·87	9·44	+0·57
Co	0·44	..	..	..	0·44	0·44	0·42	— ·02
Cu	0·04	..	..	..	0·04	0·04	0·01	— ·03
P	..	..	0·16	..	0·16	0·16	0·16	0
Cr_2O_3	..	..	..	0·50	0·50	0·50	0·50	0
MgO	..	2·07	..	..	2·07	2·09	2·59	+ ·50
CaO	..	0·65	..	..	0·65	0·66	0·46	— ·20
Na_2O	..	0·16	..	..	0·16	0·16	0·17	+ ·01
K_2O	..	0·10	..	..	0·10	0·10	0·10	0
SiO_2	..	2·76	..	..	2·76	2·78	2·89	+ ·11
Undecomposed	..	1·04	..	..	1·04	1·05	1·05	0
Total ..	90·03	8·60	0·64	0·73	100·00	100·71	..	..

BRUSH.

	Nickel-iron.	Olivine.	Schreibersite.	Chromite.	Total.	Calculated.	Observed.	Differences.
Fe	77·52	1·88	1·77	0·13	81·30	81·65	81·65	0
O	..	0·54	..	0·04	0·58	0·58	..	..
Ni	8·26	..	0·93	..	9·19	9·23	9·17	—0·06
Co	0·42	..	..	..	0·42	0·42	0·44	+0·02
Cu	0·04	..	..	..	0·04	0·04	0·08	+0·04
P	..	..	0·48	..	0·48	0·48	0·49	+·01
Cr_2O_3	..	..	..	0·36	0·36	0·36	trace	..
MgO	..	2·75	..	..	2·75	2·76	2·43	— ·33
CaO	..	0·87	..	..	0·87	0·88	1·16	+ ·28
Na_2O	..	0·21	..	..	0·21	0·21	..	..
K_2O	..	0·13	..	..	0·13	0·13	..	..
SiO_2	..	3·67	..	..	3·67	3·69	3·63	— ·06
Total ..	86·24	10·05	3·18	0·53	100·00	100·42	..	..

(Since the whole fragment analysed by Brush weighed 4·3767 grams, the composition of the stony matter is based on the analysis of 0·4399 grams.)

Summary.

36. The differences in the statements of Le Conte, Bartlett, Parke, Michler, Irwin, and Ainsa, relative to the original site of the meteoritic masses of Tucson, are all such as might easily result from simple errors

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of printing or interpretation: the masses have been known for centuries: they were found in a pass called *Los Muchachos*, which is between Tucson and Tubac, and is on the eastern side of the road: other masses of various sizes are said to be still in the pass. The results of the analyses made by Smith, Genth and Brush, show that, besides small proportions of schreibersite and chromite, there is a varying proportion (8 to 10 per cent.) of stony matter included in the nickel-iron: they are consistent with the stony matter being a lime-olivine, having approximately the per-centage composition FeO 24·07, MgO 27·37, CaO 8·67, Na_2O 2·15, K_2O 1·26, and SiO_2 36·48, and with the nickel-iron being composed of Fe 89·89, Ni 9·58, Co 0·49 and Cu 0·04.

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Abstracts.

Passage between Granophyre and Gabbro.—At Pigeon Point, Minnesota, W. S. Bayley has investigated certain fine-grained red eruptive rocks of acid nature, which occur in close association with an olivine-gabbro. (*Amer. Journ. Sci.*, (3) Vol. xxxvii., p. 55; 1889.) The red rocks comprise both even-grained and porphyritic types, and consist of two felspars, quartz, chlorite, and several subordinate constituents. They are referred to the "quartz-keratophyres" of Rosenbusch, the dominant felspar being an anorthoclase of the composition shown in column I. (by W. F. Hillebrand). More interesting is the passage traceable in the field from these acid rocks into the olivine-gabbro. This is illustrated by analyses of the two very different rocks and of intermediate varieties taken in order. These are given in columns II., III., IV., V., VI.; II. being the granophyric acid rock named by the author quartz-keratophyre, and VI. the olivine-gabbro.

	I.	II.	III.	IV.	V.	VI.
SiO_2 ...	65·00	72·42	57·98	57·88	50·69	49·88
TiO_2 ...	—	0·40	1·75	—	—	1·19
Al_2O_3 ...	18·22	13·04	13·58	—	—	13·55
Fe_2O_3 ...	2·64	0·68	3·11	—	—	2·06
FeO ...	—	2·49	8·68	—	—	8·37
MnO ...	—	0·09	0·13	—	—	0·09
CaO ...	1·06	0·66	2·01	4·68	7·94	9·72
SrO ...	—	—	trace	—	—	trace
BaO ...	—	0·15	0·04	—	—	0·02
MgO ...	0·06	0·58	2·87	—	—	5·77
K_2O ...	4·18	4·97	3·44	—	—	0·68
Na_2O ...	8·40	3·44	3·56	—	—	2·59
Li_2O ...	—	trace	trace	—	—	—
H_2O ...	0·46	1·21	2·47	—	—	1·04
P_2O_5 ...	—	0·20	0·29	—	—	0·16
Cl ...	—	—	—	—	—	trace
	100·02	100·33	99·91	—	—	100·12
Sp. gr. ...	2·577	+ 2·620	—	2·741	—	2·928

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These figures bring out well the increase in lime and magnesia, and the decrease in silica and potash; and from the field-evidence the author ascribes the phenomena to a "mutual interfusion of the basic and acidic rocks at their points of contact." He compares the acid rocks of Pigeon Point with R. D. Irving's "augite-syenites" in the Keweenaw Series. [They also seem to compare pretty closely with rocks in the English Lake district, such as the Buttermere granophyre and the Eskdale granite. The passage described is further interesting with reference to the transitions observed between granophyre and gabbro on Carrock Fell by Mr. Teall.]

A. H.

Beryllonite, a new mineral. E. S. Dana and H. L. Wells describe a new mineral from a granitic vein at Stoneham, Maine, U.S.A. It occurs in the form of imperfect rhombic crystals with numerous faces, and often twinned. There is a highly perfect basal cleavage, with less perfect pinacoidal cleavages. Hardness 5·5—6; sp. gr. 2·845; colourless to white, or slightly yellowish. The analysis agrees very closely with the formula $Na\,Be\,PO_4$. The optic axes lie in the plane parallel to *a*; and the acute bisectrix is normal to *c*. (*Amer. Journ. Sci.* (3), xxxvii., p. 23; 1889.) A. H.

Edisonite; a fourth form of titanic acid. (?) W. E. Hidden has described from the Whistnant Gold Mine, Polk Co., N. Carolina, U.S.A., some crystal fragments which he regards as a new rhombic form of titanic acid. The mineral occurs associated with rutile, anatase, xenotime, monazite, &c. The only natural faces present were a prism (angle 140° 34′) and the basal pinacoid. As placed by Des Cloizeaux, to bring out a pseudo-tetragonal symmetry, these become macrodome and brachypinacoid. Other forms are given by three pairs of cleavage-directions. The hardness is 6; sp. gr. 4·285; lustre resinous to adamantine; colour bronze-yellow to golden-brown. A careful analysis by S. L. Penfield shows that only TiO_2 (Titanic Acid) is present. (*Amer. Journ. Sci.*, (3), vol. xxxvi., p. 272; 1888.)

Mügge however has subsequently described Rutile from Snarum (and probably also from the Urals) which has a similar cleavage, but is, without doubt, ordinary Rutile, having faces of separation nearly conciding with the pyramid $\frac{9}{2}$ P∞ {902}. (*Neues Jahrb.* 1889 (1), p. 231.) It is, therefore, improbable that the mineral described by Des Cloizeaux is a new substance. A. H.

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Phonolite-pumice from the Laacher See district.—K. Busz has investigated the characters and mutual relations of several rocks in the neighbourhood of the Laacher See. (*Sitzungsb. d. niederrhein. Gesellsch.*, 11th November, 1889.) South-east of the foot of the Olbrück hill occurs a loose pale-brown tuff, consisting of fragments of pumice about the size of a pea, with pieces of Devonian slate, grains of quartz, and crystals of leucite. It encloses numerous blocks of the well-known Olbrück rock (the so-called 'nosean-phonolite,' &c.). The pumice consists largely of leucite-crystals, often rounded, the larger ones showing twin-striation. These are imbedded in a colourless or yellowish glass with augite, magnetite, and sphene. Nepheline crystals are found, and more sparingly decomposed nosean. The pumice fragments lie in a light brown ground, consisting chiefly of comminuted pumice with crystals of leucite, augite, nosean, sanidine, and biotite, and fragments of slate. This tuff compares well with the Olbrück rock, and is held to have had a common origin with it. Similar relations between pumice and phonolite are found in other localities in the district. A pumice from a road-cutting near Bell differs from the others in that the prominent white crystals are not leucite, but nosean in rhombic dodecahedra. Large crystals of sanidine occur with it. A. H.

New forms on Native Sulphur.—K. Busz (*ibid.*) describes crystals of sulphur occurring with galena from Bassick, U.S.A. They show as many as twenty-one different forms on one crystal. The pyramids (335) and (337) are observed for the first time. The pyramid (119), found by Zepharovich on sulphur from Swoszowice, is constantly present here. A. H.

Monazite as a rock-forming mineral.—O. A. Derby records monazite, the phosphate of cerium, lanthanum, and didymium, as a wide-spread accessory constituent in the gneisses, granites, and syenites of Brazil (*Amer. Journ. Sci.* (3), vol. xxxvii., p. 109; 1889). It was first discovered in the sea and river-sands of the district, and separated by washing: [sp. gr. = 5·2]. Subsequently it was obtained by the same method from the rocks *in situ*. The residue is a sand consisting of yellow grains of monazite and white zircons. One granitite yielded 0·07 *per cent.* A. H.

Strontianite and Celestine.—A Cathrein (*Zeitschr. f. Kryst.*, vol. xiv., p. 366) describes calciostrontianite (emmonite) from Brixlegg in the

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Tyrol, where it occurs in spherical aggregates of small imperfectly-formed crystals of a yellowish colour, associated with barytes. An analysis gives

$$SrCO_3\ 86{\cdot}89.\quad CaCO_3\ 13{\cdot}14\ ;$$

closely agreeing with Thomson's 'emmonite' from Massachusetts.

J. Beckenkamp *(ibid.* p. 66) describes a strontianite from the Kaiserstuhl, in Baden, which yielded 4·91 *per cent.* of CaO and 63·94 of SrO, corresponding to

$$SrCO_3\ 91{\cdot}12,\quad CaCO_3\ 8{\cdot}77.$$

This mineral occurs in bunches of needle-like crystals, and also in minute crystals having a remarkable tetrahedron-like development. Celestine also occurs.

A. H. Chester *(Amer. Jour. Sci.*, (3) vol. xxxiii., p. 284) gives an analysis by F. J. Cairns of pale-red celestine from Lairdsville, near Hamilton College, which contains

$$SrSO_4\ 84{\cdot}09\ ;\ BaSO_4\ 10{\cdot}05\ ;\ CaSO_4\ 4{\cdot}86.$$

G. Bettanini *(Riv. Sci.-Indust. di Firenze*, 1887) and G. B. Negri *(Riv. Min. e Crist. Ital.*, 1887) have made crystallographic studies of celestine crystals from Montecchio Maggiore. The former calculates the axial ratios by the method of least squares to be

$$a : b : c = 0{\cdot}77739 : 1{\cdot}00000 : 1{\cdot}27354.$$

The latter finds

$$a : b : c = 0{\cdot}77926 : 1{\cdot}00000 : 1{\cdot}28282.$$

A. H.

Rock-forming Allanite and Epidote.—In recent years, allanite or orthite has become recognised as a wide-spread primary accessory in many igneous rocks, especially in North America. Parallel intergrowths of this mineral with epidote, the allanite commonly forming the core of the compound crystal, have also been noticed, and were recorded by W. H. Hobbs as a frequent occurrence in the porphyritic granite of Ilchester, Md. (*Johns Hopkins Univ. Circ.*, No. 65; 1888). This author has more recently given a detailed account of the minerals *(Amer. Journ. Sci.* (3), vol. xxxviii., p. 223; 1889). The epidote is in yellow columnar crystals, one to three mm. long, with a brown kernel of allanite. The latter is idiomorphic, and when the epidote also shows crystal faces, the parallelism of growth is evident. The forms observed are M (001), r ($\bar{1}01$), and T (100). The allanite has high refractive index, feeble

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birefringence, and strong dispersion: its pleochroism is marked; α, light yellowish-brown; β, chestnut-brown; γ, dark greenish-brown; absorption $\gamma > \beta > \alpha$, as in epidote. The epidote gave; α, nearly colourless; β, light straw-yellow; γ, siskin-green. An analysis by W. F. Hillebrand agrees closely with Ludwig's Untersulzbach epidote, and gives very closely the formula $2\ H_2Ca_4Al_6Si_6O_{26} + H_2Ca_4Fe_6Si_6O_{26}$.

Lacroix has described precisely similar instances of intergrowth of allanite and epidote in pyroxene-amphibole-gneiss from Finisterre, pyroxene-wernerite-gneiss from the Lower Austrian Waldviertel, and wernerite-gneiss from Odegarden in Norway (*Bull. Soc. Franç. Min.* Vol. xii., pp. 138, 157, 210; 1889.) He considers both allanite and epidote primary minerals. Hobbs states that the allanite in the Ilchester rock is one of the earliest separations from the magma, but is inclined to favour a metamorphic origin for the epidote, which is often without crystal boundaries. A. H.

A Mica-peridotite from the Harz.—Besides the two chief gabbro masses of the Harz occurs a smaller one to the north-east, in the upper part of the Kaltenthal near Harzburg. Here, as elsewhere, there is a tendency in these basic rocks to separate into more and less basic portions with a definite strike. The typical norite has 49·23 *per cent.* of silica, the olivine-gabbro 46·43, the well-known 'schillerfels' or bastite-serpentine-rock (Harzburgite of Rosenbusch) 42·36. To these M. Koch (*Zeitsch. deutsch. geol. Gesell.* Vol. xli., p. 168; 1889) adds an ultrabasic rock from Kaltenthal, with the following analysis by Hampe:—

SiO_2	34·98
TiO_2	5·18
Al_2O_3	10·80
Fe_2O_3	1·42
FeO	21·33
MgO	19·30
CaO	0·43
K_2O	5·42
Na_2O	0·17
H_2O	1·28
SO_3	trace
	100·31

The specific gravity is 3·2757. The rock consists of angular or rounded grains of perfectly fresh olivine up to 2½ mm. in diameter and

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dark brown flakes of mica, in which are scattered numerous granules (up to ½ mm.) of blue-green transparent spinel, with some ilmenite. Augite and plagioclase are much less abundant accessories. The high percentage of titanic acid is not completely accounted for by the ilmenite: some of it must belong to the mica. A. H.

A new rock from the Cabo de Gata district.—Pursuing his account of the eruptive rocks of Cabo de Gata in Almeria, southern Spain, A. Osann has given a description of an interesting rock-type which occurs in the hill Cabesso Maria, 6 km. S.W. of the town of Vera, and in small patches to a distance of 8 km. further east (*Zeitschr. d. deutsch. geol. Gesellsch.* Vol. xli. p. 306; 1889.) The various patches are relics of a thin lava-flow overlying Pliocene strata, and the hill named evidently marks the source of eruption. The rock is black, with a pitchy lustre, and shows flakes of pale-brown mica up to 2 mm. in diameter. It also contains amygdaloidal vesicles filled with carbonates and elongated in the direction of flow.

The mica, which is the most striking constituent, shows in thin sections a yellow-brown colour with pleochroism: α, nearly colourless; β, pale brownish; γ, canary yellow: absorption $\beta > \gamma > \alpha$. Even basal cleavage-flakes are therefore markedly dichroic. The colouring is often zonal, the interior of a flake being either lighter or darker than the margin. The flakes are well-formed, and show no magnetite border or other evidence of resorption by the magma. There is also a second generation of mica in the ground-mass, each flake surrounded by a colourless halo in the glassy base. The mica is of the second group, with axial plane (010), small axial angle, and negative bisectrix sensibly oblique to the basal plane, a slightly oblique extinction being observable in parallel light in cross sections of the flakes. The little scales in the ground-mass are grouped in fan-like bunches.

Olivine is abundant in little colourless grains and crystals with included octahedra of brown picotite. It gives rise to carbonates, but only little serpentine. Pyroxene occurs in very pale greenish crystals belonging to the 'effusion-period.' It is remarkable for glass-inclusions in the form of parallel rods thickened at each end, and arranged nearly perpendicular to the vertical axis. Apatite is an accessory. The almost complete absence of iron-ores is striking, only small violet-brown flakes of ilmenite being rarely found. The only mineral visible in hand-specimens is the mica.

Felspar is found only in the variety from Cabesso Maria, in the form of small lath-shaped crystals, with no twinning, and with extinction-angles

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less than 18°. It appears to be not more basic than labradorite bordering on andesine. The Cabesso Maria variety has about equal parts of crystals and glass: in the normal type the latter predominates. It is in section pale-brown and globulitic, and it is not destroyed by acids.

The chemical composition of the rock is represented in column I.

	I.	II.
SiO_2	55·17	56·96
Al_2O_3	13·49	12·95
Fe_2O_3	3·10	7.58
FeO	3·55	
MnO	0·39	0·65
MgO	8·55	6·62
CaO	3·15	4·63
K_2O	1·09	4.35
Na_2O	4·43	2·22
H_2O	4·27	1·44
CO_2	3·27	1·94
	100·46	99·84

In chemical as well as mineralogical characters the rock does not agree with any of the limburgites, basalts, or andesites, but is most closely paralleled by the olivine-bearing lamprophyres, of which it appears to be a glassy, volcanic representative. For comparison the analysis II. is given of a minette from the Ballon of Alsace (by Delesse). The author considers the rock worth distinguishing as a separate type, and proposes the name *Verite*, from the town Vera. A. H.

Nephrite and Jadeite.—F. W. Clarke and G. P. Merrill have made a valuable contribution to the jade question in the form of a chemical and microscopical examination of a large suite of specimens in the Museum at Washington (*Proc. U.S. National Mus.* Vol. xi. p. 115; 1888.) These have been collected from a wide range of localities, especially in North and Central America. Four analyses were made of Alaskan implements; the average of these, which agree very closely, is given in column I. All the iron is reckoned as ferrous oxide, and the alkalies are not estimated.

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	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Ignition	1·86	1·66	0·88	0·68	1·81	0·53	0·90	0·93
SiO_2	56·68	57·05	56·78	56·87	58·88	58·18	59·18	58·33
Al_2O_3	1·55	0·85	3·22	1·50	25·93	28·53	22·96	21·63
Fe_2O_3	—	5·00	—	—	—	—	1·87	1·71
FeO	6·55	0·87	5·96	6·33	0·24	1·67		0·73
MnO	trace	trace	trace	trace	—	—	—	—
CaO	12·54	12·42	13·24	13·45	0.40	2·35	1·52	4·92
MgO	20·95	22·22	19·42	21·06	0·36	1·72	0·67	3·09
Na_2O	—	—	—	—	11·64	11·81	12·71	8·13
K_2O	—	—	—	—	0·63	0·77	trace	0·22
	100·13	100·07	99·40	99·84	100·01	100·56	99·81	99·69

These are true nephrites. For comparison four specimens of material collected *in situ* in the Jade Mountains, Alaska, were examined. The average of the analyses is given in column II. The comparison of the two columns and the identity of microscopical characters of the two sets of specimens show that the implements were probably of home origin. Nephrites from other localities, however, show a close similarity of composition: III. is the analysis of a boulder from New Zealand, IV. an implement from Robenhausen, Switzerland. The thin slices of these specimens show the usual felted and tufted aggregate of minute fibres and scales of an amphibolic mineral. The specific gravities quoted range between 2·922 and 3·015.

A number of jade ornaments from Mexico were examined. The specific gravities of twelve specimens ranged from 3·007 to 3·355, and analyses of two gave the results here cited in columns V. and VI., the former having also Cr_2O_3 0·12. These figures indicate normal jadeite, Al Na $2SiO_3$, the water being considered to replace the alkalies. The microscopic structure of these two specimens consists of a granular aggregate of greenish or colourless crystals, shattered and traversed by plates of a micaceous mineral.

Of a large collection of ornaments from Costa Rica two jadeites were analysed, from Sardinal (VII.) and Culebra (VIII.); specific gravities 3·32 and 3·27 respectively. The former showed microscopically a granular aggregate of shapeless crystals with the cleavage and optical properties of pyroxene. The latter consisted largely of matted fibres and scales, among which were imbedded crystal grains of a similar pyroxenic mineral.

The simplest practical method of distinguishing between nephrite and jadeite is by making use of the higher specific gravity of the latter. The

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authors doubt the possibility of discriminating them with certainty by their microscopical characters.

Besides these two substances, quartz, fibrolite, saussurite, etc., were found to have afforded material for implements and ornaments from various localities. A. H.

Origin of the graphite of Ceylon.—Graphite is the most important mineral product of Ceylon, and its occurrence there has been recorded and described by various writers, and especially by F. Sandberger. (*Neus. Jahrb. f. Min.*, 1887, Vol. ii. p. 12.) The mineral is coarsely lamellar or fibrous in structure, and encloses quartz, orthoclase, fibrous hornblende, mica, apatite, pyrites, weathered andesine, and chloritic kaolin, besides needles of colourless rutile and acicular pseudomorphs of ilmenite.

J. Walther has recently examined the mode of occurrence of the graphite in the Kaluganga and Kultura district, where it forms veins in a grey gneiss, which is weathered to a depth of 12 metres to a pale-red mass of kaolin, etc., the 'laterite' of the author. The complex branching veins cannot be explained as stratified masses disturbed by faulting. The author dismisses the possible eruptive origin of the graphite with Sandberger's remark that the enclosed pyrites cannot have originated at a high temperature, and that heat would have caused the rutile needles to be reduced by the carbon to metallic titanium [which seems scarcely conclusive]. The theory of an aqueous origin for the graphite is also rejected, because the gneiss and 'laterite' bordering the veins are free from graphite, and there are not even any salbands containing carbonaceous matter. It remains that the graphite was introduced into the veins in a gaseous form. The author does not suppose that it sublimed as carbon, but in the form of one of the hydrocarbons rich in that element. He compares it with the carbon formed by sublimation in the retorts of gas-works. Hydrocarbon compounds are known as exhalations in various parts of the world, and spectrum analysis proves that they play an important part in other worlds less developed than our own. Walther believes that this theory of the origin of graphite by the reducing of hydrocarbon vapours will hold good in some other localities, but does not press it as a universal theory. (*Zeitschr. d. deutsch. geol. Gesellsch.* Vol. xli. p. 359; 1889.) A. H.

Alums and other minerals in Chili.—The province of Tarapaca in Chili is known for its deposits of nitre. Prof. H. Schulze, of Santiago, has recently found there a layer of pure *blödite* (*astrakanite*) 500 m. long by

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10 to 40 m. broad, and 0·5 to 0·6 m. thick. In the same locality occurs *tamarugite* (Na_2SO_4, $Al_2S_3O_{12}$, $12H_2O$), a new half-dehydrated soda-alum with glassy lustre, forming slightly bent blades without crystal faces. *Pickeringite* ($MgSO_4$, $Al_2S_3O_{12}$, $22H_2O$), is also found in very fine fibres to a length of 40 cm. All three salts contain a small amount of cobalt, and have a rosy tint in consequence. Massive *hydroboracite* is found near the alum-deposits: the locality is Cerros pintados. In Challacollo, 50 km. farther south, *matlockite*, *cotunnite*, *percylite*, *huantajayite*, *silver-iodide*, *anglesite*, *lead-iodide*, *etc.*, have been produced by the action of saline solutions from argentiferous galena. [C. Ochsenius in *Zeitschr. d. deutsch. geol. Gesellsch.*, Vol. xli. p. 371 ; 1889.] A. H.

Heavy liquids for the separation of Minerals.—J. W. Retgers describes some new liquids which attain a higher specific gravity than those at present in use, and may be used to separate minerals whose density is greater than 3·6 (*Neues Jahrb.* 1889 (2), p. 185). The most convenient liquids at present known are Thoulet's solution of mercury and potassium iodide (Sp. gr. = 3·196), Klein's solution of cadmium borowolframate (3·28), Brauns' methylene iodide (3·30), and Rohrbach's solution of mercury and barium iodide (3·58). Retgers finds that the Thoulet, Rohrbach, and Brauns' liquids may all be made more dense by addition of iodine; and the methylene iodide may even be raised to the density of 3·65 by dissolving in it first iodoform and then iodine. All these liquids can be used cold. If molten solids are employed a much greater density can be reached. Those which are most to be recommended are mercury and potassium iodide (4·1), melting point 100°C, iodine (4·0) m.p. 113°, silver nitrate (4·1) m.p. 198°; but the most convenient of all is the mixed iodide and nitrate of silver obtained as a transparent yellow oily liquid by dissolving silver iodide in a warm concentrated solution of silver nitrate. This has a density about 5·0, and melts at the low temperature of 65°—70°; rutile and zircon float in the liquid.

Cold liquids having been used to separate the minerals lighter than 3·6, molten silver nitrate will then separate the group 3·6—4·1 which includes staurolite, pyrope, pleonaste, anatase, corundum, perowskite, and picotite; finally by means of the molten silver iodide and nitrate the group 4·1—5·0 comprising rutile, zircon, chromite, and ilmenite, can be separated, so that the only important heavy mineral remaining will be magnetite. H. A. M.

Jadeite.—The Mineral previously described as Jadeite from Piz Longhin in Bergellthal (See E. von Fellenberg, *Neues Jahrb.* 1889 (1), p.

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108) has now been analysed by Professors Rammelsberg and Meyer, and proves to be massive Idocrase, having the same composition as the Idocrase from Monzoni and several other localities. (*Neues Jahrb.* 1889 (1), pp. 229, 270.) H. A. M.

Cryptolite.—The Cryptolite which occurs in small crystals in the Apatite of Tvedestrand, and was originally described as a new mineral from Arendal, by Wöhler, has been examined by Mallard (*Bull. Soc. Franc. de Min.* 1887, x. p. 236), who finds it to have all the physical characters of Monazite, with which it is also identical in composition.

H. A. M.

Spodumene from Brazil has been the subject of careful analyses by P. Jannasch (*Neues Jahrbuch*, 1888 (1), p. 196), whose results agree closely with the previous analyses made by Dölter and Pisani, and confirm the accuracy of the formula $(Li, Na)_2O\ Al_2O_3\ 4SiO_2$. The Brazilian Spodumene is an isomorphous mixture of about 96·5 per cent. of the lithium-aluminium-silicate with 3·5 per cent. of the corresponding sodium-silicate, and contains 7·45 per cent. of lithia; the author is of opinion that all Spodumene analyses which indicate a small percentage of lithia (less than 6·5) need revision. H. A. M.

The absorption of light in crystals.—W. Ramsay (*Zeits. f. Kryst.* xiii. 1887, pp. 97-134) in an elaborate paper continues the researches of Klein and Laspeyres upon the absorption of light in epidote, and proves that in this mineral the axes of maximum and minimum absorption do not coincide with the principal axes of optical elasticity. It seems to have been generally assumed that there are three rectangular axes of maximum, mean and minimum absorption in any crystal, and that these probably coincide with the elasticity axes. In reality, light of each colour has two definite directions of vibration, for which the absorption is a maximum and a minimum; in the case of epidote the direction corresponding to least absorption for red light makes an angle of 20° with the maximum elasticity axis, while that for green light makes an angle of 35° with the same. The angle between the directions of greatest and least absorption for red light is 82°, and for green light 90°; the dispersion of the "absorption-axes" is in the opposite direction to that of the elasticity axes. H. A. M.

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REVIEW.

Handbuch der Mineralogie (Erste Lieferung), von C. Hintze. Leipzig (Veit & Comp.), 1889.

This is the first instalment of what will be a very important treatise if the author, Prof. Hintze, of Breslau, succeeds in carrying his colossal task to a successful conclusion.

Most text-books of Mineralogy commence with a "General Part" or "Introduction," which includes a necessarily incomplete account of Crystallography and Chemistry of little use to the student who can consult text-books of those subjects, and of no use to those who want a book of reference on Minerals. Prof. Hintze wisely confines himself to a complete account of each mineral from the crystallographic, chemical, and mineralogical points of view. Special attention is paid to the associations and modes of occurrence of the specimens from various localities, and here the descriptions are made more than usually interesting by arranging them, where possible, not in geographical, but in historical order.

The first part begins with the Silicates, and includes the groups of minerals classed with Olivine, Willemite, Garnet, and Topaz, together with a few others.

The amount of detailed information given may be realised from the description of Topaz, which extends over 25 pages, and includes 29 analyses, while under Lime-Iron-garnet no less than 71 analyses are quoted.

There are very complete references to original authorities, and even the names of authors from whom the figures have been borrowed are given. This is an innovation much to be recommended. The work is of course almost entirely a compilation, but is so complete that it must become a standard book of reference. Prof. Hintze hopes to complete it in 3 or 4 years, and we wish him all success in his undertaking. H. A. M.

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BERH. NAT. VER. CASSEL.	Bericht des Vereins fur Natur-Kunde. Cassel.
BOLL. SOC. NAP.	Bolletino della Società dei Naturalisti in Napoli.
BULL. SOC. SAV.	Bulletin de la Société d'Histoire Naturelle de Savoie. Chambéry.
JAHRESB. UNG. GEOL. ANST.	Jahresbericht der k. ungarischen Geologischen Anstalt. Budapest.
MATH. TERMES. ERT.	Mathematikai es Természettudományi Ertesitö Kiadja a Magyar Tudományos Akademia. Budapest.
MITTH. AK. BERL.	Mathematische und naturwissenschaftliche Mittheilungen aus den sitzungsberichten der königlich preussischen Akademie der Wissenschaften zu Berlin.
MITTH. MIN. INST. KIEL.	Mittheilungen aus dem Mineralogischen Institut der Universität. Kiel.
PROC. BATH CLUB.	Proceedings of the Bath Natural History and Antiquarian Field Club. Bath.
RIV. MIN.	Rivista di Mineralogia e Cristallografia. Padova.
TIDS. PHYS. CHEM.	Tidsskrift for Physik og Chemi. Kjobenhavn.
TRANS. INST. MIN. ENG.	Transactions of the North of England Institute of Mining and Mechanical Engineers. Newcastle-on-Tyne.
VERS. NAT. AERZT.	Tageblatt der Versammlung deutscher Naturforscher und Aerzte.
ZTS. GES. ERDK. BERL.	Zeitschrift der Gesellschaft für Erdkunde. Berlin.
ZTS. PHYS. CHEM.	Zeitschrift für physikalische Chemie. Leipzig.

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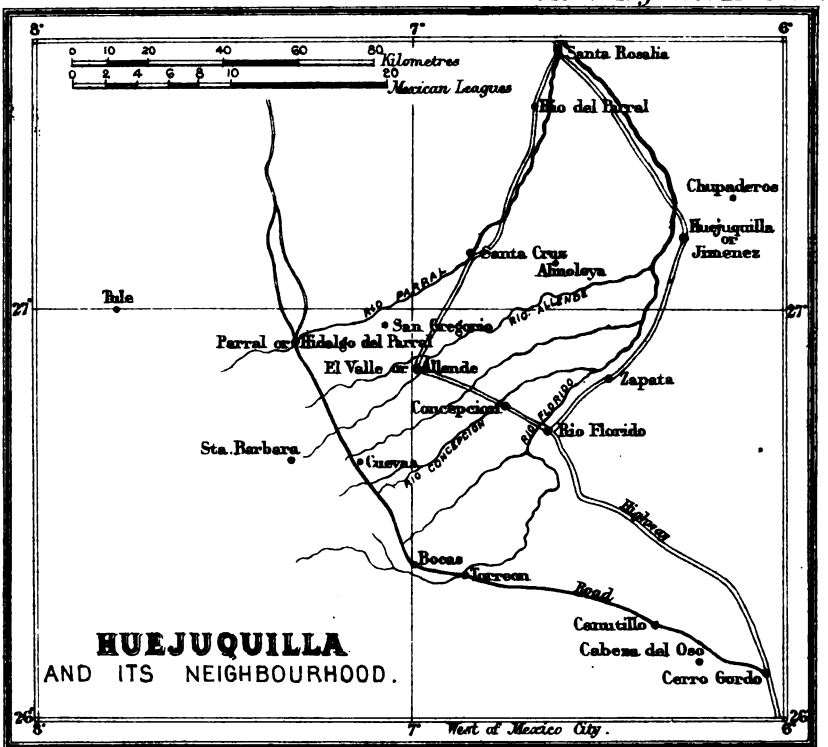

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THE MINERALOGICAL MAGAZINE
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MINERALOGICAL SOCIETY.

No. 42. AUGUST, 1890. Vol. IX.

On the Mexican Meteorites, with especial regard to the supposed occurrence of wide-spread meteoritic showers.

By L. Fletcher, M.A., F.R.S.,
Keeper of Minerals in the British Museum.

(*With maps of the region, Plates I. and II.*)

[Read May 20th, 1890.]

Introduction.

In a recent paper[1] descriptions were given of some meteoritic masses, which had been brought from the Desert of Atacama and are now in the British Museum. Several of them were independent of those preserved in other Meteorite Collections, in that they showed no signs of having been broken since their discovery; but it still remained to determine whether they might not possibly belong to meteoritic showers, of which individual masses had been already collected and described.

For this a minute investigation of the meteoritic literature of the Desert

[1] *Mineralogical Magazine*, 1889, vol. 8, p. 223.

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of Atacama was necessary. In the course of the investigation, it became clear that the prevalent belief in wide-spread meteoritic showers, whether true or untrue in general, was, as regards the Desert of Atacama, based on insufficient evidence: that in one case the wide-spreading of a shower was undoubtedly caused by a mere interchange of labels; in another by misinterpretations of the statements relative to a locality; that while the places were widely separated from which other fragments, belonging to a single type, had been brought, they were on definite and dangerous lines of traffic, along which similar fragments are known to have been carried on the backs of capricious mules: further, that the statement that "meteorites were found at every step in the Desert" had been made at a time when almost the whole of the Desert was untrodden and unexplored: finally, that the latest explorations did not suggest the existence of meteoritic masses at small distances from each other over any large area of that part of South America.

Attention was thus directed to the following facts:—(1) only nine falls of meteoric iron are known to have been observed since the year 1751; (2) not more than two masses of iron have been seen to fall simultaneously; (3) the largest (Nejed) weighed only 131 lbs.; (4) falls of stones, sometimes thousands in number, have been often observed; (5) the largest authenticated separation for the individuals of a single fall, whether of stone or iron, has been sixteen miles; (6) in some regions meteoric iron will endure for ages before rusting completely away; (7) the discovery of numerous masses of iron in certain districts may be due to the circumstance that the ground has been unexplored, or at least uncultivated, during many centuries.

It has already been distinctly pointed out by Professor Daubrée[1] that the small dispersion of a meteoritic fall is suggestive of the entry into the terrestrial atmosphere of only a single mass, afterwards fractured by the enormous resistance of the air: for the individuals of a swarm of meteoritic masses, various in form and size, would experience resistances so different in magnitude, that the residual masses would probably be scattered over areas of the earth's surface much larger than those which have characterised any of the observed falls.

The converse is not necessarily true, for a wide separation of the terminal individuals of a meteoritic fall might conceivably be due to successive fractures of a single primitive mass. And it may be worthy of remark that, but for the differential action of the atmospheric resistance, the

[1] *Études Synthétiques de Géologie Expérimentale*, *Paris*, 1879, p. 672.

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dispersion consequent on the breakage of the primitive mass would be very small, however numerous the so-called explosions, since each fragment would retain the enormous velocity belonging to it as part of the original moving body: that by simple division a single mass, or a swarm, could succeed in "dropping" fragments at distant points of the line of flight is mechanically impossible.

Remembering the close similarity in structure and material of the single representatives of meteoritic falls to those which have been picked up in hundreds or even thousands, and the identity in character of the luminous and also of the detonatory phenomena in the different cases, it is difficult to grant that the enormous disparity in the numbers of the individual masses, which have been found after different meteoritic falls, is satisfactorily explained by any possible diversity in structure or velocity of singly entrant blocks.

It cannot be said, however, that all the consequences of the entry into the terrestrial atmosphere of a heavy body, or a swarm of them, with planetary velocity, have yet been satisfactorily worked out: the determination of the maximum observed distribution over the earth's surface of masses belonging to a single meteoritic type would be useful, either as a criterion or as a confirmation of a solution of the mechanical problem.

The evidence for and against the natural occurrence, over a large area, of meteoritic masses belonging to a single and well defined type, is thus not without scientific interest: firstly, as throwing light on the possible occurrence within comparatively recent times of large meteoritic showers such as are not known to have been actually observed; and secondly, as bearing on the true relationship of meteorites and shooting stars.

Supposed wide-spread showers in other regions.

The occurrence of wide-spread meteoritic showers has been regarded as established by the distribution of meteoritic masses, not only in the Desert of Atacama, but also in Africa and Mexico.

It is true that masses of meteoric iron, rarely more than one or two hundred pounds in weight, have also been found dispersed in considerable number over the extensive territory of the United States of North America; but it has been as yet impossible, by investigation and comparison of the mineralogical characters of those masses, to obtain any reliable evidence that distant individuals have ever belonged to one meteor.

The evidence relative to a wide distribution in Africa of masses belonging to a single type is extremely slight: when examined it appears to be based solely on the brief statement, made on the authority of Captain

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J. E. Alexander,[1] "that there were abundant masses of iron scattered over the surface of a considerable tract of country." In his map the words "much iron" are inscribed close to, and on the east side of, the Great Fish River, in 26° south latitude. But this point is sixty miles from his route as marked on the map, and Alexander gives no description either of the locality or of the mode of occurrence: it is practically certain that he never saw the masses, and that the above information was given to him by a native: in any case, it is not suggestive of a distribution over an extraordinary area. This is confirmed by the reference to the iron made by Captain Alexander in a paper read to the Royal Geographical Society:[2] he states that "there is also *said to be*, to the N.E. of Bethany, near the Great Fish River, a plain covered with large masses of iron, some of which require several men to lift them. I have got specimens of this iron."

Mexican Meteorites.

But the evidence relative to Mexico is of a much more voluminous character, and is deserving of the closest attention. Mexico is remarkable beyond any other part of the earth's surface for the number and magnitude of the masses of meteoric iron found within its borders: it has been generally assumed that wide-spread showers were necessary to the explanation of their occurrence. Professor Lawrence Smith[3] came to the conclusion that masses belonging to a single meteor were distributed over hundreds of miles of country in Northern Mexico, and his conclusion has been generally accepted:[4] Professor Whitney,[5] and also Señor Urquidi,[6] regarded it as possible that a whole series of iron masses, for a distance of more than a thousand miles through Mexico and the United States, were the result of a single fall: Huntington[7] states that the fact of certain masses having been "found in places so remote from each other does not seem to preclude their having belonged to one individual, since the Rochester meteorite was seen to pass over the States of Kansas, Missouri, Illinois, Indiana, Ohio, and is supposed to have passed over Pennsylvania and

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[1] *An Expedition of Dis. Inter. Africa* (*countries of the Great Namaquas, Boschmans and Hill Damaras*), 1838, vol. 2, appendix, p. 272.

[2] *Journ. Roy. Geogr. Soc.*, London, 1838, vol. 8, p. 24.

[3] *Amer. Jour. Sc.*, 1871, ser. 3, vol. 2, p. 338.

[4] *Ibid.*: 1887, ser. 3, vol. 33, p. 116.

[5] *Proc. Cal. Ac. Nat. Sc.*, 1866, vol. 3, part 3, p. 242.

[6] *Bol. de la Soc. Mex. de Geog. y Estad.* Segunda época, 1871, vol. 3, p. 276.

[7] *Proc. Amer. Acad. of Arts and Sciences*, 1888, vol. 24, p. 34.

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New York, and thence out to sea, dropping fragments in its course. It therefore is possible that at some remote period an enormous iron meteorite may have passed over the entire breadth of the United States, the main mass reaching Mexico, but large fragments breaking off and falling during its passage across the country : " Professor Barcena[1] is further of opinion that the "peculiar property, difficult of explanation, which the Mexican soil has in attracting the meteoric irons is even noticed at present " (in the attraction of shooting stars).

The following questions thus present themselves for consideration :—

1. What meteoritic falls have been actually observed in Mexico ?
2. In what localities are meteoritic masses said to have been met with ?
3. Is our knowledge of the distribution in these localities at all precise ?
4. Is the climate favourable to the preservation of meteoritic masses ?
5. Are any falls of remote date ?
6. Have any masses been transported from their place of fall ?
7. Had the ancient Mexicans any skill in the transport of heavy blocks ?
8. Had they any respect for meteorites as bodies fallen from the sky ?
9. Is there any evidence of the wide dispersion of masses belonging to a single type ?
10. If so, is the dispersion celestial in origin or due to the action of man ?

1. Meteoritic falls actually observed.

Only the following seven falls are known to have been actually observed :—

November 24th, 1804.	Hacienda de Bocas, State of San Luis Potosi.
January, 1844.	Loma de la Cosina, State of Guanajuato.
June, 1865.	Hacienda d'Avilez, State of Durango.
June 11th, 1878.	Irapuato, State of Guanajuato.
September 17th, 1879.	Tomatlan, State of Jalisco.
June 18th, 1881.	Pacula, State of Hidalgo.
November 27th, 1885.	Mazapil, State of Zacatecas.

With the exception of Mazapil, the fallen bodies have been essentially stony in character ; in the case of Mazapil, the mass consisted of meteoric iron and weighed only about 8 lbs. : in no case were more than three fragments collected. During the same interval of time, larger showers and more numerous falls have been observed within the British Isles, which are comparatively small in area.

[1] *Proc. Ac. Nat. Sc. Philadelphia*, 1876, p. 126.

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Doubtless other meteoritic falls have been observed in Mexico, though the masses have not been preserved: as stated below, the companions of Cortes, for example, are said to have seen a meteorite at Cholula which had fallen on the neighbouring pyramid.

A fireball, probably meteoritic, caused much terror to the Mexicans in the year 1521: "many, after the siege, declared that among other prodigies, they beheld a stream of light of a blood-red colour, coming from the north in the direction of Tepejacac, with a rushing noise like that of a whirlwind, which swept round the district of Tlatelolco, darting out sparkles and flakes of fire, till it shot far into the centre of the lake" (Prescott).

2. Localities in which meteoritic masses have been found.

A statement of the precise localities in which masses, recognised as being of meteoric origin, have been met with is given below: at this stage we need merely observe that the localities are only in the following States (Plate I.):—

I. Coahuila and Nuevo Leon; II. Chihuahua; III. Sinaloa; IV. Durango; V. San Luis Potosi; VI. Zacatecas; VII. Mexico and Morelos; VIII. Oaxaca; IX. Guerrero.

3. The distribution in each locality.

Our knowledge of the distribution of the masses is much more precise for Central and Southern Mexico than for the Northern regions, more especially Coahuila. On the other hand, it is the supposed distribution of meteoric irons in the Bolson de Mapimi, Northern Mexico, that has been largely relied upon as illustrating the occurrence of wide-spread showers. It will be seen, on consideration, that until many years after the publication of the papers of Shepard and Lawrence Smith, no trustworthy information relative to the greater part of that district can have been available, and that any inferences as to wide-spread showers in that region must have been of doubtful value.

The following extracts, from works published at various times during the century, are sufficient to indicate the difficulty which would have been met with, in attempting to get reliable information as to the distribution of meteoritic masses in Northern Mexico:—

(Humboldt,[1] 1811). "The mountainous region called the Bolson de

[1] *Essai politique sur la Nouv. Espagne*, Paris, 1811, 4to ed., vol. 1, pp. 282, 289.

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Mapimi has an extent of more than 3,000 square leagues: it is from this district that the Apaches come to attack the colonies of Coahuila and New Biscay: the Bolson de Mapimi is sometimes regarded as unconquered, sometimes as forming part of the Province of New Biscay." "On the north and east of the Province of New Biscay is a strip of uncultivated country, 200 leagues in length, inhabited by Indian warriors and Independents. The border-forts erected for the defence of the colonists are too far apart, and the Indians are much dreaded."

(Ruxton,[1] 1846). "In the fall of last year, and at the present moment (1846), the Indians have been more audacious than ever was known in previous years."

"The ranchos and haciendas in Durango and Chihuahua are each enclosed by a high wall, flanked at the corners by circular bastions loopholed for musketry. The entrance is by a large gate which is closed at night; and on the flat roof of the building, a sentry is constantly posted, day and night." "Between Mapimi and Chihuahua is a large unpeopled tract of country: it once possessed several thriving villages and ranchos, now deserted and in ruins. A road from Mapimi, disused for years and overgrown with grass, leads to Chihuahua through these deserted villages."

(Bartlett,[2] 1852). "The Apaches had been more bold than usual during the spring and summer of 1852, and the whole frontier had suffered from their inroads. Many men had been killed within a few miles of El Paso del Norte, and at the astronomical observatory, 8 miles distant, a man was pierced with arrows while herding the animals within a few rods of the house. No one could venture alone with safety 3 miles from the settlement (El Paso)." "The Comanches pass across the Rio Grande into Mexico in bands of three or four hundred, and penetrate the very heart of Chihuahua; they have passed into Durango and Zacatecas, and have traversed Coahuila and Nuevo Leon. The extent of the depredations and murders committed by them would be appalling, if summed up. The depredations of the Apaches are less serious only because their numbers are less, and they have a more thinly settled country for their operations. These regions, once inhabited by a peaceful and happy population, are now deserted, and the fertile valleys they tilled are reverting to the condition of a wilderness." "The range of the

[1] *Advent. in Mexico and the Rocky Mountains*, by G. F. Ruxton, new ed., 1861, pp. 102, 111, 124.

[2] *Personal Narrative of Explor. in Texas, New Mexico, California, Sonora and Chihuahua*, New York, 1854, vol. 2, pp. 384-6, 396, 455.

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Comanches is from the Mexican States alluded to, to the buffalo region, north and east of Santa Fé. In the fall and winter season their home is near the Rio Grande, in the Bolson de Mapimi, a vast basin shut in by mountains on the west." "Every small party coming through (to El Paso) from San Antonio had been attacked by the Comanches. At no time had so much alarm been felt." "The Bolson de Mapimi being now (November 1852) in possession of the Comanches and Lipans, who are some thousands strong, it is not considered safe for parties of less than one or two hundred to attempt the journey from Huejuquilla to Parras by the short route across its south-western corner."

In the decade 1860-70 portions of the frontier were still disturbed by Indian hostility.[1]

Under the above circumstances it is obvious that no evidence of wide and plentiful distribution of meteoritic masses in Northern Mexico has ever been available: any inference as to the occurrence of widespread falls must have been made merely from the presence of similar masses in a few widely separated localities.

4. Is the climate favourable to the preservation of meteoritic masses?

Like the Desert of Atacama, Mexico is a table-land, but still more lofty and extensive: the table-land gradually slopes downwards in a northerly direction, the capital being 7,600 feet, Durango 6,630 feet, Chihuahua 4,600 feet, and El Paso del Norte 3,800 feet, above the sea-level. Hence the air is exceedingly dry, and the climate unusually favourable to the preservation of meteoric iron. Ward[2] says:—"With a cloudless sky and a brilliantly pure atmosphere, there is a great want of moisture and little luxuriancy of vegetation."

In the discussion of the Atacama meteorites, it was proved that even in the still drier atmosphere of that region, meteoric stones could only escape disintegration for a very limited interval of time.

5. Are any of the falls of remote date?

It will be shown that the history of some of the Mexican masses goes back to very distant times. One was found in an old tomb in the ruins at Casas Grandes: it was wrapped in the same kind of cloth as envelops the bodies found in the adjacent tombs, and must have been buried there

[1] *Encyclop. Britann.*, 1888, vol. 23, p. 820.

[2] *Mexico*, by H. G. Ward, Esq., Her Majesty's Chargé d'Affaires in that country during 1825-7, 2nd ed., London, 1829, vol. 1, p. 8.

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before Mexico was conquered by the Spaniards. In the cleft of another mass is to be seen an ancient chisel of "copper," the material used by the Aztecs for their arms, axes, and tools in general. Two small worked specimen, belonging to the Aztec period and made of meteoric iron, are exhibited in the Museum of Mexico.[1] At least one of the masses in the south of Chihuahua was known long before the latter part of the sixteenth century. Those in the Valley of Toluca were visited about 1776. The mass called Descubridora was found before 1780: that of Zacatecas was examined in 1792: that of Charcas was described in 1804.

It is quite possible that with the exception of the small piece which fell at Mazapil in 1885, not a single one of the Mexican iron masses has fallen since the Spaniards obtained possession of the country. The masses thus seem to be nearly permanent in their material, and may have been lying for any number of centuries in the places where they have been found.

6. *Transportation of masses.*

Some of the masses have been first noticed by scientific men after the removal from their place of fall. The mass already referred to as found in a tomb at Casas Grandes was clearly not *in situ:* according to one account, it is lenticular in shape and 18 inches in diameter; according to a later account its weight is such that 26 yoke of oxen were used to haul it to the village. The masses met with at Saltillo, Potosi and Cerralvo, were discovered in forges in use as anvils: the large masses of San Gregorio, Concepcion, Descubridora, Charcas, Zacatecas and Yanhuitlan, are all known to have been moved more than once, and for considerable distances. The possibility of similar removals in times prior to the conquest of Mexico by the Spaniards cannot be entirely disregarded.

7. *Mechanical skill of the ancient Mexicans.*

The following extracts[2] are of interest as proving that before the arrival of the Spaniards there existed, in some parts of Mexico, men capable of moving immense blocks of heavy material when required.

"An immense circular block of carved stone was disinterred in 1790 in the great square of Mexico. This colossal fragment, on which the calendar is engraved, shows that they had the means of settling

[1] *Anales del Museo Nacional de México*, 1882, vol. 2, p. 473.

[2] *History of the Conquest of Mexico*, by W. H. Prescott, London, 1878, pp. 58, 68, 194, 233.

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the hours of the day with precision, the periods of the solstices and of the equinoxes, and that of the transit across the zenith of Mexico." "It consists of dark porphyry, and in its original dimensions is computed to have weighed nearly fifty tons. It was transported from the mountains beyond Lake Chalco, a distance of many leagues, over a broken country intersected by water-courses and canals. In crossing a bridge, which traversed one of these latter in the capital, the supports gave way, and the huge mass was precipitated into the water, whence it was with difficulty recovered. The fact that so enormous a fragment of porphyry could be thus safely carried for leagues in the face of such obstacles, and without the aid of cattle, for the Aztecs had no animals of draught, suggests to us no mean ideas of their mechanical skill and of their machinery, and implies a degree of cultivation little inferior to that demanded for the geometrical and astronomical science displayed in the inscriptions on this very stone."

This remarkable stone, which had been buried by the Archbishop of Mexico (1551-9), is now preserved in their National Museum: its weight is estimated at 482 quintals or about 24 tons. We may incidentally remark that Alfredo Chavero[1] in a long series of papers has lately published the results of a most elaborate study of the hieroglyphs upon the stone: he comes to the conclusion that it cannot have been a calendar-stone at all, and was more probably a votive offering to the Sun.

And again—"The fortification was a stone-wall, nine feet in height and twenty in thickness, with a parapet a foot and a half broad. It extended more than two leagues. The work was built of immense blocks of stone, nicely laid together without cement; and the remains still existing, among which are rocks of the whole breadth of the rampart, fully attest its solidity and size. This singular structure marked the limits of Tlascala, and was intended as a barrier against the Mexican invasions."

The pyramid of Cholula may be cited as another illustration of mechanical skill:—"The perpendicular height is 177 feet; the base is 1,423 feet long; it is square and covers about 44 acres: the platform on the truncated summit is more than an acre in area: on the platform stood a sumptuous temple. Travellers still gaze with admiration on it as the most colossal fabric in New Spain."

Humboldt,[2] who gives a figure representing its appearance in 1802, states that the pyramid was already built when the Aztecs reached that

[1] *Anales del Museo Nacional de México*, 1879, vol. 1, p. 353, 1880, vol. 2, p. 3 *et seq.*

[2] *Vue des Cordill. et Mon. d. Peup. indig. de l'Amér.*: Paris, 1810, p. 24.

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part of Mexico (A.D. 1190): its construction was attributed by them to the most ancient time known to their tradition—that of the Toltecs, five centuries before. It is now an almost shapeless hill, with a church at the top.

Finally, we may cite the statement of Humboldt[1] relative to the ruins of Mitla:—"But what distinguishes the ruins of Mitla from all the other remains of Mexican architecture, is the series of six columns of porphyry, placed in the middle of a large hall and supporting the roof. These columns, almost the only ones found in the New Continent, show the infancy of art. They have neither pedestal nor capital. Their height is 5 metres: yet each is formed of a single mass of amphibolic porphyry. The *débris*, accumulated during centuries, conceals the columns to one-third of their height."

For such a people, a transportation of even the largest of the observed masses of meteoric iron would not have been impossible.

8. *Reverence for meteorites.*

It is well known that in various parts of the Old World, meteorites have been regarded, from the earliest times even to our own day, as objects for reverence and worship. The same is true of the New World. As evidence of such veneration, it may be mentioned that in the Aztec creed the creation of mankind was associated with the fall of a body from the sky. Andrés de Olmos,[2] who went to Mexico immediately after the conquest and made a careful study of its languages and traditions, states that, notwithstanding the diversity of worship in different provinces, there was an almost universal belief that the goddess Citlalicue gave birth to a *tecpatl* which fell from the sky to the earth at a place called Chicomoztoc (Seven Caverns): that from the *tecpatl* came sixteen hundred gods and goddesses: and that, after a complaint to Citlalicue that there was no one to worship them, mankind was created for their service.

Tecpatl occurs frequently among the Aztec hieroglyphs, and is there used to indicate one of the days of the month: representations of the various hieroglyphs, including *tecpatl*, have been given by Manuel Orozco y Berra;[3] the hieroglyph *tecpatl* is a figure of the sharp stone which was used as a knife by the sacrificing priest.

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[1] *Essai politique*, &c., Paris, 1811, vol. 1, p. 264.

[2] *Monarquia Yndiana*, by Torquemada: Sevilla, 1615, vol. 2, pp. 81-2.

[3] *Anales del Museo Nacional de México*, 1880-2, vol. 2, p. 224.

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According to Humboldt,[1] the companions of Cortes are said to have seen a meteorite at Cholula, which, enveloped in a cloud of fire, had fallen from the clouds upon the pyramid; and he adds that it had the shape of a toad. I have been unable to trace the original authority for his statement. Humboldt refers also to an ancient tradition of the Aztecs, recorded in a Vatican manuscript of Pedro de los Rios, that the building of the pyramid of Cholula had been begun by Xelhua in commemoration of a Great Flood, which only he and six brother-giants had survived: the gods angered by his audacity sent down fire from heaven, whereupon the building was discontinued and the edifice was dedicated to Quetzalcoatl, God of the Air.

Muñoz Lumbier[2] refers to the Cholula meteorite as having been placed on the summit of the pyramid for the purpose of worship.

It is possible that there has been a confusion of traditions relative to a lightning stroke and a meteoritic fall, and even that a "divine" stone has been assumed by a translator to be of celestial origin.

The respect of the ancient Mexicans for native iron, whether known to be of meteoric origin or not, is illustrated in the careful envelopment and burial of the large mass of iron at Casas Grandes. One of the large Chihuahua masses was believed by the Mexicans of the sixteenth century to have been deposited by their deity for use as a landmark. In other parts of North America, proofs of the same veneration are to be found: in an Indian mound in Oktibbeha County, Mississippi, during an excavation for Indian antiquities, a small piece, weighing 5¼ ozs., was discovered in 1857;[3] this may have been buried merely as a personal relic, for several ear-ornaments and implements, made of meteoric iron, were found in the mounds of Little Miami Valley, Ohio, in 1883.[4] The Brazos mass, weighing 320 lbs., removed to San Antonio in 1836, had been long known to the Comanches. It had been set up as a *fetich*, or object of veneration, at a spot where several converging trails intersected: it was the custom of all who passed by to deposit upon it beads, arrow-heads, tobacco, and other articles as offerings: the Indians "revered it as foreign to the earth and coming from the Great Spirit."[5]

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[1] *Vues des Cordillères et Monuments des Peuples indigènes de l'Amérique*, Paris, 1810, p. 32.

[2] *Los Aerólitos de Chihuahua*, México, 1880, p. 6.

[3] *Amer. Jour. Sc.*, 1857, ser. 2, vol. 24, p. 293.

[4] *Ibid.*, 1887, ser. 3, vol. 33, p. 228.

[5] *Trans. Ac. Sc. of St. Louis*, 1857-60, vol. 1, p. 622. *Amer. Jour. Sc.*, 1884, ser. 3, vol. 28, p. 286.

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The Iron Creek mass, weighing 386 lbs., removed about 1869, was also "greatly venerated by the Indians, who made offerings to it of beads, trinkets and knives, before setting out on hunting or warlike expeditions."[1]

Hence it would have been far from surprising if a religious and skilful people, like the Aztecs, had transported meteoritic masses from their original sites for the purpose of worship: the large blocks of stone on Salisbury Plain furnish a good example of the transportation of heavy masses for great distances by a still more ancient race.

9-10. Natural or artificial dispersion of masses belonging to a single type.

In very few cases is there any evidence at all of wide distribution of masses belonging to a single type. The large masses of San Gregorio, Concepcion and Chupaderos, all in Chihuahua, are very similar in their external characters, and probably belong to a single fall: the extreme separation is about 66 miles, but it will be proved that the two former masses have been transported for some distance to their present sites. Masses belonging to a single type, and probably the results of a single fall, have been brought from widely separated places in Coahuila and its neighbourhood; masses belonging to another type have been brought from places in the Valley of Toluca and also at considerable distances therefrom: there is very strong evidence, however, that in these two cases the dispersion has been artificial. In the remaining cases there is nothing suggestive of wide-spread showers.

Tucson, though formerly within the Mexican border, is now in the United States: but the view has been expressed that the masses of iron, long preserved there, are products of a meteor to which various Mexican masses have been supposed to be due. The history and description of the Tucson masses, as already given in a separate paper,[2] are however sufficient to establish the complete independence of the Tucson and Mexican falls.

The history and distribution of the various Mexican masses are given below: it has been necessary to enter into considerable detail, for it will be seen that the identity of a mass, referred to in a given description, can often be established only by attention to some point which in itself is of merely trivial import.

History and distribution of the Mexican meteoritic masses.

In the value of his contributions to a general scientific knowledge of

[1] *Proc. & Trans. Roy. Soc. of Canada*, 1887, vol. 4, sec. 3, p. 97.

[2] *Mineralogical Magazine*, 1890, vol. 9, p. 16.

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Mexico, Burkart takes a place next to Humboldt: in particular, his repeated inquiries after Mexican meteorites have had for their result a large addition to our information.[1] Lately Antonio del Castillo, Director of the School of Mines of Mexico, has done a great service, by placing on record a list of the meteoritic masses known to still exist in that country.[2]

It will be convenient here to indicate some of the conclusions, to which we are incidentally led by the following detailed investigation :—

1. The large "Durango" mass, mentioned by Humboldt, inquired after for years by Burkart, and vainly searched for by many people in the course of the century, is undoubtedly identical with one of the Chihuahua masses at present known.

2. The "Durango" mass of Karawinsky was found at the Labor de Guadalupe, a few leagues from Durango City.

3. The "Venagas" mass, mentioned by Lawrence Smith in 1854, but up to the present untraced, is certainly identical with the Descubridora mass.

4. The mass supposed to be near Los Zapotes is identical with that of Zacatecas.

5. The so-called Chalco and Cholula masses are identical with that of Yanhuitlan; and the Misteca fragments are undoubtedly parts of the same.

6. The identity of the locality of the Coahuila masses mentioned by Shepard with that of the masses collected by Butcher, long suspected, is beyond doubt.

7. The situation of the so-called "Sancha Estate" is now determined.

8. The Rio Florido mass is probably identical with that of Concepcion.

We now proceed to the detailed discussion of the meteoritic masses found in the several States.

I. States of Coahuila and Nuevo Leon.

The known meteoric irons of Coahuila may be grouped as follows:—

1. The masses which Shepard designated by the name *Bonanza;*

2. The masses collected by *Dr. Butcher;*

3. Masses brought from *Santa Rosa* (*de Muzquiz*), but of which the previous history is matter of inference;

4. The *Sanchez Estate* mass.

With the above must be considered

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[1] *Neues Jahrb. f. Mineralogie*, 1856, p. 257; 1857, p. 53; 1858, p. 769; 1866, p. 401; 1870, p. 673; 1871, p. 851; 1874, p. 22.

[2] *Catalogue Descriptif des Météorites du Mexique*, Paris, 1889.

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5. The *Fort Duncan* mass (from the Texas side of the Rio Grande): and conveniently also
6. The *Potosi* mass (Nuevo Leon), and
7. The *Cerralvo* mass (Nuevo Leon).

It will be sought to prove that all the masses belong to a single fall, have been brought to Santa Rosa from a district of small area in the Bolson de Mapimi, and have been artificially distributed, chiefly for the use of blacksmiths.

Physical features of the Bolson de Mapimi.

The Coahuila masses have been found in the Bolson de Mapimi, which, as already shown, was long frequented by the Apaches, Comanches and Lipans. The name was formerly given to a large extent of country bounded on the north by the Rio Grande, and having the towns of Huejuquilla, Mapimi and Santa Rosa, on its western, southern and eastern borders, respectively. The following description by Wislizenus will give some idea of its general features as seen from the southern base:—[1]

"Leaving Mapimi our road now led to a very open and level valley, which belongs to the famous Bolson de Mapimi which commences here. To the right of our road, or east, at the distance of from 3 to 5 miles a steep and high mountain-chain of limestone rises, and another chain to our left from 10 to 15 miles. Both chains gradually diverge, but especially the eastern which seems to run towards the north-east and to return thence towards the south-west at an angle, leaving a large *cul de sac* or pouch (Bolson) in the middle, from which form the country has probably received its name. The pouch-like slope of the country extends most likely as far as the Rio Grande. Passing over a ridge on our road, I enjoyed the most distant view over the Bolson de Mapimi. All around us was an immense chaparrál plain, and in the distance of from 15 to 20 miles ahead of us the Rio Nasas, which runs towards the north into the above mentioned pouch, and forms there the large Laguna de Tlagualila (on maps generally called Lake Cayman). Neither the lake nor the northern end of the Bolson was to be seen from my place of observation; but the outlines of the surrounding mountains, disappearing on the most distant horizon, seemed to extend towards the north to about 80 miles in length, and towards east and west to an average breadth of 30 miles. As to the physical properties of the Bolson, the general impression is that it represents a low, flat, swampy country, and a mere desert, which

[1] *Memoir of a tour to Northern Mexico, connected with Col. Doniphan's Expedition in* 1846-7. [Senate Doc.], Washington, 1848, p. 67.

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is but partly true. The soil in the Bolson is less sandy, and better than in the higher country; in the valley of the Nasas, especially, is a black rich soil and most luxuriant vegetation. At Mapimi the elevation was found to be 4,487 feet, at San Sebastian 3,785, at San Lorenzo 3,815, at San Juan 3,775, at El Pozo 3,990, and at Parras 4,987."

1-5. The masses probably belong to a single fall.

The probable singleness of the fall is established by the unity of the rare characters of the masses. When a polished face of a Coahuila iron is etched, the Widmanstätten figures, so common in meteoric irons, are found to be everywhere, or almost everywhere, completely absent: in their place are seen the far less frequent systems of fine and straight parallel lines (called Neumann lines) extending across the etched face; the angles between the different systems, of course, varying with the direction of the section. The etched faces of specimens of the Sanchez Estate, Bonanza, Butcher and Fort Duncan irons, now in the British Museum, are indistinguishable in their features.

Looking to the rarity of such features on the etched faces of meteorites; and to the fact that the above masses have been brought from a region of the earth's surface comparatively small in area; and remembering that no mass belonging to the more common meteoritic type has yet been brought from Coahuila, while none, or at most one, belonging to the Coahuila type have been brought from any other part of Mexico; it is impossible to escape the conclusion that probably all have fallen simultaneously, whether the fall was wide-spread or not.

After investigation of the modes of fracture of meteoric iron, Huntington[1] came to the conclusion that, notwithstanding the similarity of the etched faces, the differences of fracture were such that it was impossible to regard the Sanchez Estate block and those collected by Dr. Butcher as ever having belonged to a single original mass: hence he assigned the Butcher irons to one fall and the Sanchez Estate to another, expressing the view that the latter was a wide-spread one, and was further represented by the mass found at Fort Duncan, and by others found hundreds of miles farther away, at Allen County in Kentucky, and Chattooga County in Georgia. Later observation, however, has shown that the variation of crystalline character in different parts of one block is quite sufficient to prove that the fracture is a discriminating character to which little weight can be attached.

[1] *Proc. Amer. Acad. of Arts and Sciences*, 1888-9, vol. 24, pp. 34, 313.

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1-3. The Bonanza, Butcher, and Santa Rosa masses.

The localities of the Bonanza and Butcher masses are identical.

The accounts given relative to the localities of the Bonanza and Butcher masses differ so much from one another that, without a minute comparison of the various statements, a decisive conclusion as to the identity or otherwise of the two localities is impossible: the difficulty is not diminished by the puzzling fact that in none of his papers does the later author make the slightest reference to the descriptions given by the earlier one in the same periodical, although the later expedition was probably a direct result of the account of the earlier visit. As previous discussion has left the identity of the localities uncertain, it is desirable to enter into such detail as will suffice to establish the identity in a decisive manner.

The masses referred to in Charles Upham Shepard's papers[1] had been visited by Major E. M. Hamilton: Shepard's statements are founded, partly on a letter from Professor Forrest Shepherd, who had been recently travelling with Hamilton in Nuevo Leon, and partly on later information derived directly from Major Hamilton himself; Lawrence Smith's accounts[2] are based on descriptions furnished by Dr. H. B. Butcher, who had himself collected several masses, and had transported them to the United States.

The differences in the accounts are in respect of (*a*) the number and sizes of the masses existent at the localities, (*b*) the distance of the localities from Santa Rosa.

(*a.*) *Number and sizes of the masses.*

1. The Bonanza masses:—"In an open space, about one quarter of a mile square, partially overgrown with palmetto palms, might be seen fourteen ponderous masses of native iron, the largest of which rises upwards of four feet above the ground, having the form of a bee-hive—being five feet in diameter where it enters the soil, and into which it descends for an unknown depth. Major Hamilton informed me that he excavated on one of its sides to the distance of 18 inches, without discovering any diminution of its diameter" (Shepherd's letter to Shepard, 1866). "Major Hamilton saw thirteen pieces; twelve of which had never been removed, and one small mass of about seventy-five pounds that had been carried to the village of Santa Rosa. The largest mass

[1] *Amer. Jour. Sc.*, 1866, ser. 2, vol. 42, p. 347; 1867, ser. 2, vol. 43, p. 384.

[2] *Ibid.*, 1869, ser. 2, vol. 47, p. 383; 1876, ser. 3, vol. 12, p. 107.

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projects two or two and a half feet above the ground, and is some three feet long and a little less in width. How far it is buried in the earth is unknown. Some of the smaller of them are estimated to weigh between 2 and 8 thousand pounds." (Hamilton's letter to Shepard, 1867.)

2. The Butcher masses:—"I have returned fully successful, and am making preparations to send on the iron. They consist of eight pieces, varying from 290 lbs., which is the smallest, to 654 lbs., which is the largest, making a total of nearly 4,000 lbs. Before the explosion, the weight must have been much greater, as it is not probable that I have secured the whole, and we know some was taken away by the Indians, who thought they found large masses of silver, and carried their specimens to Santa Rosa." (Dr. Butcher, 1868.)

It is difficult to believe that the masses collected by Butcher, varying in weight between 290 and 654 lbs., can have been identical with any of those estimated by Hamilton to weigh at least 2 or 3 thousand pounds. As Butcher remarks, it is improbable that he secured all the specimens; and indeed it would be easy for some to have escaped attention. Hamilton himself says that the masses were distributed over an area between one and two miles in diameter: in Shepherd's version of Hamilton's statement, the space is stated to be a quarter of a mile square. Butcher says:—"The plain in many places is cut up with deep ravines; several of the specimens of iron were found among the stones and sand at the bottom of the ravines, and during heavy rains were washed or covered with water. It is, however, only in wet seasons that the water is found remaining in the ravines and depressions of the valley."

The differences in these statements of the number and sizes of the masses, though unsatisfactory, are not themselves sufficient to prove that the localities mentioned by Hamilton and Butcher are distinct.

(*b.*) *Distances from Santa Rosa.*

Shepherd gives a diagram in illustration of Hamilton's route, and the following distances:—"From Santa Rosa westerly to Naciemento (*i.e.* Nacimiento) 40 miles, more or less. From Naciemento westerly or north-westerly about 15 miles to a gap through the mountains called Puerta Santana (*i.e.* Puerto Santa Ana). From the Puerta, northerly for 60 miles, along the valley, past a spring to the termination of the mountain on the left; and thence around the end of the mountain, passing a second spring, by a north-west route for a distance of about 50 miles towards an apparent junction of the mountains."

This makes the distance from Santa Rosa to be 165 miles. On the

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other hand, Butcher estimated the locality visited by himself as about 90 miles from the town.

The difference is, however, quite explicable as due to error of estimation. On what appears to be an excellent map, published by Garcia Cubas, the distance from Santa Rosa to Nacimiento is shown as 22 miles (instead of "40 miles more or less"); while the distance from Nacimiento to Puerto Santa Ana is given to be much less than 15 miles: hence it is clear that the estimated distances given in Shepherd's letter are of little value in establishing a difference of the localities.

Indeed, the indirect and direct statements made to Shepard are themselves very different; for according to the latter, apparently published as a correction of the former, the place was "about thirty or forty miles north of Santa Rosa, but much farther to the west," a statement very difficult to interpret.

(*c.*) *Direction from Santa Rosa: features of the locality.*

Both Hamilton and Butcher travelled into the mountains in a direction north-west of Santa Rosa; and their descriptions of the physical features of the locality itself are almost identical.

(*Shepherd.*) "And thence Major Hamilton travelled along the valley towards an apparent junction of the mountains; and where the valley becomes narrow, to an open space, about one quarter of a mile square, partially overgrown by palmetto palms."

(*Butcher.*) "The spot is in an alluvial valley, or plain, between two ranges of high mountains running parallel with each other, varying in distance from one to three miles."

(*d.*) *Hamilton and Butcher were not original discoverers.*

The existence of masses of iron about 90 miles north-west of Santa Rosa had long been known at that town.

"Meteoric iron is known to exist about 90 miles north-west of Santa Rosa. An American resident of this town, Dr. John Long, called my attention to a piece weighing some 25 lbs. which was then in possession of a Mexican. It is said that the whole surface of the area, embracing about 30 acres of land, where the deposition of this valuable mineral occurs, is covered with blocks of it, of greater or less extent, some containing as much or even more than 36 cubic feet." (Arthur Schott, 1857.)[1]

"According to an oral statement of Professor Posselt, meteoric iron

[1] *Report on the U.S. and Mex. Bound. Survey* (W. H. Emory), 1857, vol. 1, part 2, p. 34.

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exists in the vicinity of Santa Rosa: it is partly in large blocks, partly among the rolled stones, over a considerable area." (Wichelhaus, 1863.)[1]

The fragment analysed by Wichelhaus was taken from a specimen which had been placed in the Heidelberg Collection: the mass must have been a very small one, for there are now only 293·6 grams of Santa Rosa iron preserved there.

"Dr. John A. Veatch saw in 1849 a large mass of iron at Santa Rosa, which was then in use as an anvil at a blacksmith's shop, and was informed that many pieces of native iron had been used there for various purposes. The mass which Dr. Veatch saw was of about the size of an ordinary anvil. It was said to have been brought from the mountains north-west of the town." (Letter to Prof. Whitney, 1866.)[2]

"Residents in the vicinity told Major Hamilton (1867) it had only once before been visited by any traveller, and this was fifteen years ago, when an Englishman had been deputed thither, in an official capacity, to determine whether the iron could be applied to any useful purpose." (Shepard, 1867.)

"According to a son of Dr. Long, shortly after 1837 an Indian brought a piece, weighing 10 or 12 lbs., into Santa Rosa, supposing it to be silver, having found it some 90 miles north-west of the town." (Butcher, 1868).

The following is clearly another account of the same incident:—

"One of my guides relates as a fact that at that time (1837) a Lipan Indian was riding one of their small ponies through the valley, when his stirrup struck against one of the masses, causing a ringing sound like silver. He dismounted, and was confirmed in his opinion of silver, and took away a piece, 10 or 12 lbs. in weight, which he carried into Santa Rosa to sell." (Butcher, 1868.)

(*e.*) *Hamilton and Butcher were guided to the same place.*

Hamilton and Butcher both started from Santa Rosa: they went with the specific intention of seeing masses, the existence of which had long been a matter of common report in that town: Butcher, at least, hired guides at Santa Rosa: both entered the mountains in a north-westerly direction. It is unlikely that more than one route through so dangerous a region can have been known to the inhabitants of Santa Rosa at that date; and it would probably be the most natural route, and therefore the one used

[1] *Pogg. Ann.*, 1863, vol. 118, p. 631.

[2] *Proc. Calif. Ac. Nat. Sc.*, 1866, vol. 3, part 3, p. 241.

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by the Indians themselves. Further, it is improbable that the inhabitants of Santa Rosa were so venturesome as to depart far from this natural route for the purpose of exploring the Bolson.

In fact, both Hamilton and Butcher seem to suggest that the place was reached by keeping along a particular valley, and Dr. Butcher says distinctly that it was near the regular Indian trail:—"I hired eight Mexicans and two Indians as guides, and started into the mountains, which are distant about 35 miles, and found the iron about 90 miles from Santa Rosa. As no vehicle could be got into the mountains by the route we entered, I spent two days in exploring a new road whereby the ox-teams could bring them out. My party were in considerable danger while in the mountains, as we were two miles from the regular trail, when some 300 Indians went through with a large number of their stolen horses."

Passages of the Rio Grande in this district.

A route having the characters described by Hamilton and Butcher has every claim to be regarded as a natural one, and would lead to places where the Rio Grande is known to be fordable; and between Presidio del Norte and Eagle Pass not many parts of the Rio Grande, to which the trail doubtless led, could be readily crossed by the Indian bands.

Lieutenant Michler,[1] who surveyed this part of the river, reports as follows:—

"From this valley (in the vicinity of Fort Leaton, near Presidio del Norte), we suddenly enter the range of the Bofecillos Mountains, through which the river has found or forced a passage, forming extensive rapids at its entrance. The cañon of the Bofecillos Mountains is less rugged in its character than those met with subsequently. Comanche Pass, the most celebrated and frequently used crossing place of the Indians, was found to be just below this Bofecillos Range: here broad, well-beaten trails, lead to the river from both sides. Below the crossing, the river passes through a country varying but little from that which was met with above. The San Carlos Mountains rise in front to a considerable height. The passage of the river through these mountains is grand and imposing. From the edge of the cañon the river may be seen far below, at a distance so great as to reduce it in appearance to a mere thread; and from this height the roar of the rapids and falls is scarcely perceptible. The stream is hemmed in by the cañon for ten miles, and then leaves it with the same

[1] *Rep. on the U.S. and Mex. Bound. Sur.* (W. H. Emory), 1857, vol. 1, part 1, p. 80, *et seq.*

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abruptness that marks its entrance. As the descent of the river by boats was here impracticable, a *détour* was rendered necessary, and the river was again reached at a point some twenty miles below the lower termination of the cañon. It was here found necessary to cross the mule-train from the Mexican side: this was effected, though with considerable difficulty, at one of the usual crossings of the Indians. Near this point, above and below, the country is more open. After passing the Los Chisos Mountains, the survey was carried on with less labour than was previously encountered until we reached the Sierra San Vicente. Through these mountains the river forces its way, forming a cañon that equals the San Carlos in many places both in ruggedness and grandeur. Some sixty feet above the level of the river-bottom is situated the old Presidio San Vicente, long since abandoned and now crumbling to decay. After the Sierra San Vicente was found a country cut up with deep *arroyos*, presenting to the survey almost insurmountable obstacles. Passing these *arroyos* a wild valley, nearly at right angles with the course of the river, preceded the approach to the cañon of Sierra Carmel (Cármen), another of those rocky dungeons in which the Rio Grande is for a time imprisoned. No description can give an idea of the grandeur of the scenery through these mountains. Beyond the Sierra Carmel, the river seemed to pass through an almost interminable succession of mountains: cañon succeeded cañon: the valleys, which alone had afforded some slight chances for rest and refreshment, had become so narrow and devoid of vegetation that it was quite a task to find grass sufficient for the mules." "It was next to an impossibility to approach the river for the next twenty miles of the survey, this section being literally cut up by deep *arroyos;* steep hills, covered with rocks of igneous origin, intervene and jut into the water's edge. From the end of this section the country undergoes a great change: the formation is limestone, and the river forces its way through a deep cañon nearly twenty miles in length, its banks being composed of high perpendicular masses of solid rock. *Arroyos* of the same structure, at many places, open into the river; in following its course we had frequently to make *détours* of 25 and 30 miles, in order to advance our work a few hundred feet. Then came the first break in the cañon, and the crossing being fordable, formed an accessible pass for the Indians into Mexico. This ford is known as the Lipan crossing, and the Lipans often visited us here. Afterwards the bed is narrow and hemmed in by continuous and perfect walls of natural masonry, varying from 50 to 300 feet in height. Not unfrequently we had to travel for miles without being able to find a spot on which to land."

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Other assumptions would be necessary.

Finally, we may remark that, if the two localities are distinct, it is necessary to assume that, although both localities were known to guides at Santa Rosa, the guides to each locality had no idea that the locality known to them was distinct from that known to the guides to the other, for there is no record of two localities having been ever mentioned at the town; and further, that if the two places were on the same Indian trail, Hamilton was taken by the Santa Rosa guides past the vicinity of the Butcher masses, which, though smaller and fewer, were identical in general character with those he was going so far to see, and that not one of them was pointed out by a guide or attracted his own attention.

The localities are identical.

From this analysis of the statements it appears that only one conclusion can be arrived at—namely, that the masses visited by Hamilton and Butcher were in a single locality; and that the masses brought from time to time to Santa Rosa for sale, or to be worked in the smithies, had been got from the same limited area.

From Butcher's description, it would seem that the locality was near the place now marked in Garcia Cubas' map of Coahuila as the site of a rancho called *San José de las Piedras* (latitude 28° 42′ N., longitude 3° 43′ W. of Mexico City).

4. The Sanchez Estate mass.

This mass, weighing 252 lbs., now in the Smithsonian Institution at Washington, was figured and described by Professor Lawrence Smith in 1854-5.[1] The mass had been taken to the United States by Lieutenant D. N. Couch (not Gouch), who made some explorations in Northern Mexico during the winter 1852-3[2]: he found the mass in use as an anvil at Saltillo: "it was said to have come from the Sancha Estate, some 50 or 60 miles from Santa Rosa: various accounts were given of the precise locality, but none seemed very satisfactory: it is stated that where this mass was found there are many others of enormous size." Genth also analysed a fragment of this mass, but under a misapprehension makes the mistake of saying that it had been brought from New Mexico:[3] probably the label had been inscribed *N. Mexico*.

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[1] *Amer. Jour. Sc.*, 1855, ser. 2, vol. 19, p. 160.

[2] *Smithsonian Report for* 1854, pp. 15, 86.

[3] *Ibid.*, p. 15; *Amer. Jour. Sc.*, 1854, ser. 2, vol. 17, p. 239.

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We have pointed out above that Dr. Veatch had seen a mass of meteoric iron in use as an anvil at Santa Rosa in 1849; and that it was then known at Santa Rosa that masses of large size were to be got from the mountains northwest of the town. Saltillo is a town having now 26,000 inhabitants, and is more than a hundred miles south of Santa Rosa, which has a present population of 3,350.

Cost of anvils in Northern Mexico.

Before the introduction of railways, anvils and other heavy goods which needed to be imported, would cost large sums for carriage to places so difficult of access from the coast as the towns of Northern Mexico.

The difficulty of obtaining iron at places like Santa Rosa in the early part of the century, is well illustrated by the experience of Phillips, who required some cast-iron pipes for the pumping engines at Catorce, a place comparatively easy of access from Santa Rosa and Saltillo. There was only one route north of Jalapa by which a carriage could ascend to the table-land from the east coast, and that was by way of Monterey and Saltillo: by this route Phillips had conveyed the pumping engines themselves to Catorce, exactly twelve months being necessary for their transport from London. Unluckily, cast-iron pipes for use with the engines had been forgotten, and Phillips learned at Catorce that the nearest iron-foundry was at Cincinnati on the Mississippi. To get the pipes Phillips left Catorce for Cincinnati in November 1824, received there the last of the castings in May 1825, and spent from May 1825 to February and March 1826 in transporting them to Catorce.[1]

An anvil would thus be comparatively cheap in Northern Mexico, if the distance of transport could be reduced to two or three hundred miles; and we might expect that the blacksmiths within a considerable distance from Santa Rosa would be supplied from that town, so long as portable masses of meteoric iron were obtainable.

The carriage of a meteoritic anvil from Santa Rosa to the other towns of Northern Mexico would be a trivial matter, compared with the trouble and the danger from Indians incurred during the transport of the mass to Santa Rosa itself.

Again, the greater the distance from Santa Rosa to which the anvil was carried, the less accurately would the position of the original locality be known; the estimates of distance given by Hamilton are a sufficient proof that no stress can be laid on the difference between the "sixty

[1] *Mexico*, by H. G. Ward, 2nd ed., 1829, vol. 2, p. 417.

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miles" stated at Saltillo and the "ninety miles" stated at Santa Rosa: while the statement that "where this mass was found there are many others of enormous size" distinctly points to the locality already known to the inhabitants of Santa Rosa.

Situation of the Sanchez Estate.

The only difficulty is suggested by the mention of what appears to be a precise definition of locality, namely "Sancha Estate." Burkart long ago pointed out that *Sancha* was not a Mexican name, and must certainly have been mentioned in mistake: he suggested the possibility of the correct name being *Sanchez;* but no one has hitherto been able to discover to what the name Sancha or Sanchez Estate can have referred.

The following extracts suggest an interpretation:—

"San Lorenzo is a town of about 1,000 inhabitants. Most of the property belongs to Señor Sanchez, a rich Mexican, who received us well and seemed to be favourable to the Americans." (Wislizenus, 1846-7.)[1]

"Soon after leaving we saw through an opening in the hills on our left, about a mile distant, the hacienda of Patos. This place is the property of Don Jacobo Sanchez, and is said to be the finest in the State of Coahuila. This gentleman is said to be the owner of three quarters of the landed property in the State, including several large and valuable haciendas, well stocked with cattle, mules and horses. He has lost large numbers by the Indians; and, I am told, has made a claim on the United States for a million and a half of dollars as an indemnification for these losses. The lands of Don Jacobo extend in a continuous line more than a hundred miles." (Bartlett, 1852.)[2]

Patos is 36 miles west of Saltillo: both Patos and San Lorenzo are on the highway between that town and Chihuahua City.

At the time of Couch's visit (1852-3), the Sanchez Estate would thus be well known at Saltillo; and an inhabitant of that town might be pardoned for treating the term Sanchez Estate as synonymous with the State of Coahuila itself: even if the blacksmith had got the mass from someone employed on the Sanchez Estate, there would still remain the practical certainty that the individual was one who had business relations with Santa Rosa, a town through which passed considerable traffic between Saltillo and Texas, by way of Eagle Pass, on the Rio Grande.

It may thus be inferred with considerable approach to certainty that the

[1] *Lib. cit.*, p. 70.

[2] *Lib. cit.*, vol. 2, p. 492.

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Sanchez Estate mass had originally been found in the locality afterwards visited and described by Hamilton and Butcher.

5. The Fort Duncan mass.

This mass, weighing 97¼ lbs., was found in 1882 by Mr. Cusick while stationed at Fort Duncan, Texas; Fort Duncan is 140 miles east of the locality specified by Dr. Butcher. Cusick[1] says:—

"I was returning to the garrison from a short trip in the vicinity when I casually noticed a round-looking boulder that seemed to have a metallic appearance. I had it brought to the fort by one of the privates, who found the task not an easy one. The mass was on the land of a Mr. Wieste on an ancient terrace on the American side of the Rio Grande."

Hidden, to whom we owe the description of the mass, regards it as representing a distinct fall, but Huntington,[2] pointing out the insufficiency of his reasons, holds that the mass is an outlying member of a wide-spread shower, of which the masses to the north-west of Santa Rosa formed part. No one can compare two large etched faces belonging to the Fort Duncan and Coahuila irons without concluding that the identity of character is complete, and that the rarity of the character points to a probable simultaneity of fall; but it by no means follows that the fall was naturally wide-spread. Masses belonging to the Coahuila fall have been known, as already explained, since 1837 or soon after, so that the Fort Duncan mass, if really due to the same meteor, must have already had a minimum terrestrial existence of nearly half a century before it was found by Cusick: it is portable, for the weight is comparatively small. We have seen that much larger masses were long ago dispersed from Santa Rosa to greater distances than Eagle Pass, though in the opposite direction, for use as anvils. Further, as already remarked, Santa Rosa was a town through which passed much traffic from the eastern side of the Mexican table-land to Texas: the Eagle Pass, where Fort Duncan is situated, was the place where the river was crossed.

It is not at all impossible that the Fort Duncan mass was carried across the river by Indians or Mexicans for sale or use in Texas; was acquired, and afterwards forgotten or thrown away, by a predecessor of Mr. Wieste; and eventually re-discovered by Cusick.

(6 and 7.) The Nuevo Leon masses.

We have said that masses from the north-west of Santa Rosa may be

[1] *Amer. Jour. Sc.*, 1886, ser. 3, vol. 32, p. 304.

[2] *Ibid.*: 1887, ser. 3, vol. 33, p. 115.

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looked for in the smithies for considerable distances round that town. In fact, two anvils of meteoric iron have been seen in Nuevo Leon, within easy reach of Saltillo: still they have not been scientifically examined, and may possibly not be identical in character with those of Coahuila.

The first was mentioned in 1856 to Shepard by McDermot,[1] who had seen an anvil of meteoric iron in use at Cerralvo, District of Oriente, Nuevo Leon, in 1847: he likened it in general appearance to the Orange River mass, which weighed three hundredweight, and was then under inspection by him. The carriage from Saltillo to Cerralvo would be downhill, and would present no practical difficulty.

The second was seen by Weidner at the hacienda of Potosi, District of Galeana, Nuevo Leon: he estimated it to weigh about 200 lbs., and said that the shape was that of a quadrangular pyramid: it was mentioned by him in 1870.[2] There is a highway between Saltillo and the hacienda of Potosi, and the distance is about 70 miles: Potosi is also within easy reach of Catorce where meteoric iron has likewise been found.

Both masses have since been lost sight of.

The Santa Rosa meteor of 1837.

Lawrence Smith[3] published the following detailed account of a meteor which had been observed at Santa Rosa in 1837:—

"'In a letter dated September 8th, 1868, Dr. Butcher writes, from information received from the son of Dr. Long, who had resided many years at Santa Rosa, that in the fall of the year 1837 there appeared over the town a most brilliant meteor, having a north-west direction. He describes it as most beautiful, lighting up the whole horizon, with a trail of brilliant light following in its progress. Shortly after its disappearance among the distant mountains, they heard a rumbling sound, immediately followed by a tremendous explosion. From the report, he thought it fell and exploded as it reached the earth, somewhere between Santa Rosa and the mountains, a distance of some thirty-five miles; and the next day he started with friends to examine the route, hoping to find it. After two days' severe and rough riding they abandoned the search and returned to town. Shortly afterwards an Indian brought a piece (of meteoric iron) weighing ten or twelve pounds into Santa Rosa, supposing it to be silver,

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[1] *Amer. Jour. Sc.*, 1856, ser. 2, vol. 21, p. 216.

[2] *Neues Jahrbuch für Min.*, 1871, p. 854; *Catalogue Descriptif des Météorites du Mexique*, par Castillo, Paris, 1889, p. 9.

[3] *Amer. Jour. Sci*, 1869, ser. 2, vol. 47, p. 384.

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having found it some ninety miles north-west of the town, being in the same direction in which Dr. Long and his friends had been exploring, the doctor having been deceived as to distance, he only going to the base of the mountains, instead of crossing it and then following the valley for some forty miles further."

Though Long's description points to a meteoritic fall at a place north-west of Santa Rosa, it cannot be legitimately assumed with Long and Butcher that the fall must be identical with that to which the meteoric iron found in a north-west direction from the town was due. If such identity could have been assumed, it would have sufficed to establish that the masses brought from Sanchez Estate, Fort Duncan, Potosi, and Cerralvo, were not parts of a wide-spread fall, but had been either transported to those places, or had belonged to distinct meteors.

Chemical analyses of the Coahuila masses.

The following results have been obtained on analysis of fragments of the Coahuila masses :—

	Sanchez Estate.			Near Santa Rosa.				Fort Duncan.
	"New Mexico," Genth,[1] 1854. S.G. 8·130.		Smith,[2] 1854–5. S.G. 7·81.	Wichelhaus,[3] 1863. S.G. ——.	"Bonanza Iron," Shepard,[4] 1867. S.G. 7·625.	"Butcher Iron." Smith,[5] 1869. S.G. 7·692.	Lupton,[6] 1885. S.G. ——.	Mackintosh,[7] 1886. S.G. 7·522.
	I.	II.						
Iron ..	96·17	95·92	95·82	96·07	97·9	92·95	91·86	94·90
Nickel ..	3·07	3·57	3·18	3·26		6·62	7·42	4·87 by diff.
Cobalt ..	0·42		0·35	0·55	2·1	0·48	0·50	
Phosphorus	..	..	0·24	1·05		0·02	0·27	0·23
Residue ..	..	0·57	..	..		..	..	..
	99·66	100·06	99·59	100·93	100·00	100·07	100·05	100·00

Notwithstanding the numerical differences in the above results, Lawrence Smith was quite prepared to recognise the chemical identity of the Sanchez Estate and Butcher irons, and said (1869) that the separation of the iron and nickel in his analysis (1854-5) of the former was probably imperfect.

[1] *Amer. Jour. Sc.*, 1854, ser. 2, vol. 17, p. 239.
[2] *Ibid.*, 1855, ser. 2, vol. 19, p. 160.
[3] *Pogg. Ann.*, 1863, vol. 118, p. 631.
[4] *Amer. Jour. Sc.*, 1867, ser. 2, vol. 43, p. 385.
[5] *Ibid.* 1869, ser. 2, vol. 47, p. 383.
[6] *Ibid.*, 1885, ser. 3, vol. 29, p. 232.
[7] *Ibid.*, 1886, ser. 3, vol. 32, p. 304.

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Literature relative to other characters of the Coahuila masses.

In addition to the literature already cited we may mention the papers by Lawrence Smith, on the occurrence of daubréelite, *Amer. Jour. Sc.*, 1876, ser. 3, vol. 12, p. 107; and of a nodule of chromite, *Ibid.*, 1881, ser. 3, vol. 21, p. 461; and those of Brezina on the intergrowth of troilite and daubréelite, on the Reichenbach lamellæ, *Sitzungsb. Ak. d. Wiss. Wien*, 1881, vol. 83, div. 1, p. 476, and on natural planes of separation, *Ibid.*, 1882, vol. 84, div. 1, p. 282.

II. State of Chihuahua.

The meteoric irons of Chihuahua, mentioned in literature, belong to one or other of the following:—

1. *The Casas Grandes mass.*
2. *A mass exhibited in 1876 at the United States International Exhibition.*
3. *The group between Presidio del Principe and Cuchillo Parado.*
4. *The group near Huejuquilla or Jimenez.*

1. The Casas Grandes mass.

Casas Grandes, or Casas Grandes de Malintzin, is the name given to an ancient town and fortress, which commanded the last passage from the North to the Mexican table-land: it is situated in the District of Galeana, and is 125 miles, in direct line, south-west of El Paso del Norte.

From the accounts given by Márcos de Niza, Coronado, Espejo and others, it is well established that at the time of the conquest of Mexico by the Spaniards, in the sixteenth century, the country was inhabited in the fertile valleys, to districts far north of Santa Fé, by Indians who had attained to a comparatively high degree of civilisation, were given to agriculture, were clothed with woven fabric, and lived in large towns consisting of houses which were several stories in height and were built of sun-dried brick. The Valley of Mexico itself is known to have been peopled from the North; and it has been supposed that extensive ruins, still existing between the Valley of Mexico and the country north of the Rio Grande, indicate places at which there were prolonged halts during the migration southwards.

One of these ancient relics is at Casas Grandes de Malintzin.

The first mention of the discovery of a mass of meteoric iron among the ruins at Casas Grandes was made by Tarayre,[1] who reported in 1867 as follows:—

[1] *Archives de la Commission Scientifique du Mexique*, Paris, 1867, vol. 3, p. 348.

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"A very important discovery has been made in the great temple of Casas Grandes by Müller, the Director of the Mint of Chihuahua. An excavation, made in one of the chambers of the labyrinth, brought to light, at a small depth, a lenticular mass of meteoric iron, 50 centimetres in diameter, wrapped with care in cloths, similar to those which enshroud the ancient corpses in the tombs of the same locality. The neighbouring tombs are chambers built of masonry: the horizontal section being an ellipse with diameters of 1·5 and 1 metres, and the height 1 metre. In each case the body is seated on the base of the tomb, and has the knees raised: it is enveloped in cloth made of fibres, which recall those of the agave; and around it are deposited objects which belonged to the deceased when alive, such as necklaces, collars, bracelets, and pottery."

Another account was given in 1873 by Mr. M. Pierson,[1] United States Vice-Consul at El Paso del Norte, from which the following is extracted:—

"Some three or four years since, a party of the inhabitants of the town of Casas Grandes, as a matter of curious speculation, commenced excavating in the old ruins there. One more fortunate than the others drifted into a large room, in the middle of which there appeared a kind of tomb made of adobe-brick. Renewing his excavations, he found a large mass of meteoric iron in the middle of the tomb, carefully and curiously wrapped with a kind of coarse linen. Twenty-six yoke of oxen were mustered, and as many or more strong log-chains, and the meteorite was hauled to the town of Casas Grandes. It measures 2 feet 6 inches square, and is supposed to weigh 5,000 lbs."

Until a more complete scientific examination of the Mexican meteorites has been made, it will be impossible to say from what locality this mass may have been transported by the ancient inhabitants of Casas Grandes.

The Casas Grandes mass has not been heard of since the date of Pierson's letter: on inquiry at El Paso, I learn that Pierson is now dead, and that there is no remembrance in that town of the circumstances recorded by him.

The description given by Pierson would not be inappropriate to the mass next mentioned.

2. A mass exhibited in 1876 at the United States International Exhibition.

An uncut block of meteoric iron, estimated to weigh about 4,000 lbs., is

[1] *Smithsonian Rep. for* 1873, p. 419.

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preserved at Washington, in the United States National Museum. Dr. F. W. Clarke recalls that it was exhibited among the Mexican minerals in the United States International Exhibition of 1876, and was said to have been brought from the State of Chihuahua.[1] I am indebted to Dr. Clarke for a photograph showing at once this Chihuahua mass and the ring-shaped one from Tucson: by measurement of the photograph and comparison with the known dimensions of the latter mass, it follows that the former, a roundish block, is about 28 inches wide and 88 inches high.

Its history previous to 1876 is as yet untraced.

Professor Barcena, while at Philadelphia as Commissioner for the Mexican part of the Exhibition, read a paper before the Academy of Sciences relative to the Mexican Meteorites: he made no reference either to the Casas Grandes mass or to the one then being exhibited in Philadelphia, and this is difficult to account for unless the two masses were regarded by him as well known to be identical. Still it is unsafe to place much reliance on negative evidence, for no direct reference was made by him to the existence of the immense San Gregorio mass.

The mass cannot have belonged to the Presidio del Principe group; for, as will be seen below, the remarks of Professor Barcena implied that up to 1876 none of the group had been removed from the locality.

The only other large Mexican mass, mentioned in literature but now unaccounted for, is that of Rio Florido; but, as shown below, there are grave doubts as to whether the Rio Florido mass had ever a real existence as distinct from that of Concepcion.

3. The group between Presidio del Principe and Cuchillo Parado.

All that is known of this group is the following:—

Cornejo[2] (1869-70) says:—"A mass of meteoric iron was seen by José Salazar Ilarregui between Cuchillo Parado and Presidio del Principe: it attracted one pole of a magnet and repelled the other: in this place are numerous other masses of smaller size."

Mention was also made of them, in 1876, by Professor Mariano Barcena[3]:—

"Meteoric irons of various dimensions are found in the vicinity of the

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[1] *U.S. Centennial Commission. International Exhibition*, 1876. *Reports and Awards*. 1880, Washington, vol. 3, group 1, p. 369.

[2] *La Naturaleza*, 1869-70, vol. 1, p. 256.

[3] *Proc. Ac. Nat. Sc. Philadelphia*, 1876, p. 122.

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Presidio del Principe, in the State of Chihuahua: the inhabitants of that State have promised to send some of the masses to the city of Mexico."

It may be observed that José Salazar Ilarregui (or Y Larregui) was in 1854 the Mexican Commissioner for the Survey of the United States and Mexican Boundary.[1]

Presidio del Principe is not shown in the latest maps; but in older maps, for instance Humboldt's, it is placed 45 miles directly north of Chihuahua City, and thus in the same parallel of latitude as Cuchillo Parado, from which it is distant about 100 miles in a westerly direction.

4. The Huejuquilla or Jimenez group.

We may incidentally mention that the iron of this group was known at the beginning of the present century as "Durango iron," and that one of the masses was described by Humboldt, through a misunderstanding of the term, as being near Durango City: this point will be established later.

Huejuquilla, the nearest town to the largest members of this group, is the capital of the District of Jimenez. According to Bartlett,[2] though the name of the town, as given on the maps, was already (1852) Jimenez (after the Mexican patriot of that name), the town was only spoken of in the neighbourhood by its old Indian title, pronounced as Wa-hu-ke-yah: in literature the word is met with in various forms, *e.g.* Huajuquillo, Huejoquillo, Huexuquilla, Huejuquilla, Hejuquilla, Haxuquilla, Guajuquilla and Guayuquilla. There is now at the town a station called Jimenez, belonging to the Mexican Central Railway, and the old name may possibly fall into disuse; but as the old Indian title is used in all the references quoted in the present paper, it will be convenient to employ it throughout, and to select the form *Huejuquilla* adopted by the Mexican Postal Authorities.

The masses are the most wide-spread of any recognised group, and the wide dispersion is generally accepted as a natural one: the history of the masses thus requires minute consideration, if we are to get a reliable estimate of the maximum observed distance of dispersion for a single meteoritic fall.

The following, except that of Rio Florido, are known to still exist:—

a. A large mass now at the hacienda of San Gregorio.

b. A large mass now at the hacienda of Concepcion.

c. A large mass said to have been seen many years since at Rio Florido.

d. Two large masses now at the rancho or hacienda of Chupaderos.

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[1] *Rep. on the U.S. and Mex. Bound. Survey* (W. H. Emory), 1857, vol. 1, part 1, p. 35.

[2] *Lib. cit.*, vol. 2, p. 453.

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e. A small fragment brought from Sierra Blanca.

f. A small fragment brought from the rancho of Tule.

Sizes of the above masses.

	Length.	Breadth.	Height.	Estimated Weight.
	Metres.	Metres.	Metres.	Kilograms
Chupaderos (*a*) ...	2·5	2	0·4	15,600
,, (*b*) ...	2·15	1·1	0·5	9,290
Concepcion ...	1	1	0·4	3,130
San Gregorio	Conical: diam. of base 1·2		1	11,560
Rio Florido ...	Said to be about half the size of Concepcion			
Sierra Blanca ...	Small fragment			
Tule	Small fragment			

From Chupaderos to San Gregorio in direct line is 66 miles: Tule is still more remote from Chupaderos being 42 miles farther away beyond San Gregorio.

Do the masses belong to a single fall?

We know as yet very little of the figures produced by etching polished surfaces of these masses: the information, so far as it goes, is not unfavourable to the unity of the fall, for though a minute fragment of the Concepcion mass experimented upon is said to yield no Widmanstätten figures, while on the other hand the San Gregorio, Sierra Blanca and "Durango" fragments present a very definite octahedral structure,[1] it has been granted that a satisfactory specimen of the Concepcion mass has not yet been available for the purpose of scientific examination.

Large masses of meteoric iron are so rare, however, that it is difficult to believe that four of the largest masses of meteoric iron yet found on the earth's surface can have fallen within this limited district at different times; and the external appearances of the masses, as shown in the excellent photographs kindly sent me by Don Antonio del Castillo, are so very similar, owing to the presence of numerous enclosures of troilite, that the lingering doubt as to the singleness of the fall must disappear.

As pointed out later, the evidence relative to the small Tule fragment is of a very unsatisfactory character, and can be allowed little weight.

[1] *Beschreibung und Eintheilung der Meteoriten zu Berlin* (Rose); 1864, p. 64: *Die Meteoriten-Sammlung in Wien* (Brezina); 1885, p. 71: *Proc. Amer. Ac. of Arts and Sciences*, 1888, vol. 24, p. 35.

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The region near Huejuquilla, Concepcion and San Gregorio is favourable to transport.

Ruxton[1] says:—"The first day's march from Durango led through a wild uncultivated country (1846), with large plains of excellent pasture, but not a symptom of cultivation." Two days later, his march was "to the rancho of Yerbaniz, through the same uncultivated plains, surrounded by sierras, and passing by a ridge from one into another, each being as like the other as twins. For a thousand miles the aspect of these plains never varied, and the sketch of the plain of Los Sauces would answer for the plain of El Paso, and every intermediate one between Durango and New Mexico." "The plains, generally 10 to 20 miles in width, are divided from each other by an elevated ridge, but there is no perceptible difference in the elevation of them from Chihuahua to El Paso. The road is level except in crossing these ridges."

Having regard to the mountainous character of the region on the west of the table-land, and the few crossing places on the Rio Grande, it is seen that the above route would be one naturally selected for the traffic between Mexico City and the provinces to the extreme north of New Spain. This traffic was already a large one at the beginning of the present century: Humboldt[2] says:—"Thousands of mules arrive every week at Mexico City from Chihuahua and Durango, carrying silver, leather, soap, a little wine from El Paso del Norte, and grain."

Between Rio Florido and Santa Rosalia, two places on this line of traffic, the usual route was by way of Concepcion, El Valle de San Bartolomé (or Allende), Santa Cruz, and Rio del Parral: another road, instead of passing through El Valle de San Bartolomé, went through Huejuquilla, but was less used. As the latter route was taken by Bartlett for his caravan, the two roads cannot have been very unequal as regards facility for transport: probably the former was generally taken as passing through the important town of El Valle. At the present time there is a cart-road between Chupaderos, Huejuquilla and El Valle. (Plate II.)

The country thus presents no obstacle to the transport of masses from the neighbourhood of Huejuquilla to either Concepcion or San Gregorio.

A. The San Gregorio mass.

The existence of native iron near Huejuquilla has long been known.

Relative to the masses now at Chupaderos, Castillo in his list of existing

[1] *Lib. cit.*, pp. 108-9, 162.
[2] *Essai cit.*, vol. 2, p. 689.

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Mexican meteorites writes as follows:—"According to the history of Philip II., the discovery was made in 1581 by the explorer Antonio de Espejo." On investigation, however, it appears that only a single expedition was made by Espejo, and that he did not start off from El Valle de San Bartolomé till Nov. 10th, 1582; further, in the report of his expedition, he makes no mention of any masses of iron, and, as he followed the course of the river Conchos, it is unlikely that he was ever in the immediate neighbourhood of Chupaderos itself.[1]

As there appeared to be some mistake, the statement relied upon by Castillo was searched for in various histories, and at last found in the "Historia de Felipe Segundo, Rey de España," by Luis Cabrera de Cordoba.[2] The following is a literal translation of the passage:—

"Francisco Vasquez Coronado was sent by the Viceroy, in the year 1544, with a large number of attendants and horses, and made a brief survey (of New Mexico); but not so Friar Márcos de Niza, who acted as guide, for he entered upon the conversion of the Indians so boldly that he was put to death, as was discovered afterwards. Up to the year 1581, no further attempt to conquer the region was made by the inhabitants of New Spain: Don Lorenzo Xuarez de Mendoza, Count of Coruña, the Viceroy, then made a beginning by sending Francisco Vasquez Chamuscado with soldiers and friars of the Franciscan Order: as the friars were unwilling to retire with the soldiers, and persisted in preaching, they were put to death by the barbarians. In this year Espejo, and afterwards Castaño, and Captain Francisco de Leiva Bonilla, went upon discovery without (the requisite) license: the last mentioned was followed for a hundred leagues by Captain Don Pedro de Cazorla, who at the time was acting as governor, and he was ordered not to enter New Mexico under penalty of being denounced as a traitor. So great was the desire that the King should permit this conquest to be made, that many knightly claimants offered their lives and estates with Christian zeal. * * * By resolution of his Majesty, on the recommendation of the Viceroy, the commission was granted to Don Juan de Oñate with the title of Adelantado. * * * They reached the farthest villages on the borders of New Biscay, where there is a tradition of the Indians that, when they were coming from New Mexico to people the Old, their deity in the form of an aged woman placed there a

[1] *Hakluyt's Collection of the Early Voyages, Travels and Discoveries of the English Nation*, London, new ed., 1810, vol. 3, p. 457.

[2] Madrid, 1619, lib. 13, p. 1163: also *Edicion publicada de Real orden*, Madrid, 1876-7, vol. 2, p. 677.

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remarkable landmark of seemingly more than 800 quintals (hundredweight) of iron, whereupon some returned to their mother-country and the rest went on to people New Spain. And, for their boundary and peace, they were divided by this wondrous landmark, set up in a desert, in latitude 27½ degrees, as lustrous as refined silver. The Adelantado entered with 80 carts, many kinds of grain and seed, and splendid soldiers, some unmarried, and others married and with families: they marched with great toil, not knowing the proper roads to take; and at the end of seven months they reached the province they were making for."

According to the latest maps Huejuquilla is in latitude 27° 10′, so that there can be no doubt that one of the masses of the Huejuquilla group is here referred to.

Owing to the want of clearness of the above statement, it would be easy to make the wrong inference that the iron was discovered in the year 1581 by Espejo and Oñate.

The Expedition of Espejo.

A more precise account of the course of events, however, is the following, obtained from the report of Espejo's expedition published in 1586:—

Friar Agustin Ruiz, who was living at El Valle de San Bartolomé, having heard of the existence of other peoples farther north, set out in 1581 with two other friars and eight soldiers to convert the Indians: they reached the region since called New Mexico, and shortly afterwards one of the friars was put to death: the soldiers refused to go farther and decided to return; Ruiz and his companion, being unwilling to accompany them, were left behind. On the return of the soldiers to El Valle de San Bartolomé, the friars there were anxious to send relief to the two brethren left behind; and Espejo, a rich inhabitant of Mexico, and a native of Cordova, who happened to be then at the mines of Santa Barbola (*sic*) or Barbora (*sic*), agreed to take charge of the expedition: having obtained the requisite license, he set off on Nov. 10th, 1582, from El Valle de San Bartolomé "with 115 horses and mules, much arms and ammunition and some attendants." The friars had been put to death before the arrival of the expedition: Espejo eventually returned in July 1583, and an account of his journey was published at Madrid in 1586.

The Expedition of Oñate.

But the expedition made by Don Juan de Oñate was a totally different

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one; for he set forth, many years afterwards, not to inspect, but to obtain possession of and colonise the new province. According to a letter, written by Tribaldus Toletus[1] in 1605, Don Juan left Old Mexico "in the year 1599 with an armie and carriages of five thousand men, in which number boyes, women, young men and souldiers are included. He carried also great store of vituals with him, stockes of sheepe and goates, herdes of oxen, and all things necessarie for life, also horses and armour and other things which in these kinds of expeditions ought to be provided."

As we have already seen that Don Juan marched slowly and was seven months on his journey, his arrival at the iron-landmark, if the letter of Tribaldus Toletus be correct, may have been either in 1599 or 1600, and more probably in the latter year.

Inscription on the Concepcion mass.

If the great colonising expedition of Oñate had really passed the iron-landmark in the year 1600, it would have been probable that the landmark was really the Concepcion mass, and another possible explanation could have been given of some marks still visible on that iron.

Urquidi,[2] the owner of the hacienda of Concepcion, says (1871):—

"Among the various marks, there is an inscription, made with some nicety and regularity, saying, "A. 1600."

Bartlett,[3] who saw the mass in 1852, says:—

"On the top, which is quite smooth, is an inscription bearing the date 1600; but I was unable to make out a single word of it, so much has it been defaced by hammering and the addition of many crosses. It is said that the inscription gave some account of the removal."

It has since been established, as shown later, that the Concepcion mass was transported a distance of many leagues to the vicinity of that hacienda on 29th April, 1780: hence it is conceivable that the inscription might have been a commemoration, not of the removal, but of the passage of the specimen by the expedition of Oñate in the year 1600: the "nicety and regularity" of the inscription are suggestive of the industry and careful workmanship so important an expedition would have had at its command: in any case the inscription was probably made before the

[1] *Purchas his Pilgrimes in five bookes, &c.*, London, 1625. Fourth part, The Eighth booke, chap. III., pp. 1565-7.

[2] *Boletin de la Sociedad Mexicana de Geog. y Estad.* Segunda época, México, 1871, vol. 3, p. 275.

[3] *Lib. cit.*, vol. 2, p. 457.

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removal in 1780, otherwise the removal itself would not have been forgotten so soon as was actually the case.

Such a connection between the Concepcion mass and the expedition of Oñate has already, I find, been independently suggested by Muñoz Lumbier,[1] a copy of whose rare paper I owe to the kindness of Castillo: we shall see, however, that the suggestion, though apparently a natural one, is not well founded. The list of the Mexican meteorites was published by Castillo when at Paris far away from his own library: doubtless his reference to Espejo was a trick of memory, and he was intending to quote from the paper of his former pupil, Muñoz Lumbier, in which the extract from Luis Cabrera de Cordoba's History of Philip the Second is given.

The date of Oñate's expedition.

There is an extraordinary difficulty, however, in ascertaining the real date of departure of the colonising expedition of Don Juan de Oñate. Ludovicus Tribaldus Toletus, whose letter is dated so soon afterwards as 1605, gives the year 1599 on the basis of a manuscript volume of Andrew Garcia Cespedes, "who hath not obtained leave to publish it, for they will not have these things particularly to come to light." Luis Cabrera de Cordoba, also a contemporary (1559-1623), with access to important documents, though giving, as we have seen, minute details of the expedition, makes no mention of the year of its departure. According to the manuscripts of Padre Geronimo de Zarate Salmeron,[2] whose journal was made public in 1629, Don Juan de Oñate set out from Mexico City to New Mexico in 1596, and in 1599 started from New Mexico on an expedition farther north, in search of the reported city of Quivira. The years 1591, 1595, 1598, have also been accepted for the date of his departure from the City of Mexico. On the other hand, the petition of Don Juan to the King of Spain for permission to colonise New Mexico is said to have been dated as late as 21st September, 1595: the decree of the King confirming the capitulation and agreement, made between the Viceroy and Don Juan, is dated San Lorenzo, 8th July, 1602: the approval of this decree by the Royal Audience of New Spain was given in Mexico City on June 20th, 1604.[3]

It seems, on the whole, that Geronimo de Zarate Salmeron, who spent

[1] *Los Aerólitos de Chihuahua.* México, 1880.

[2] *Documentos para la Historia de México.* Tercera Serie. México, 1856, vol. 1, pp. 23-26.

[3] *The Spanish Conquest of New Mexico.* By W. W. H. Davis. Doylestown, Pa., 1869, p. 264.

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eight years in New Mexico shortly after the colonisation, is most likely to be correct, and that the expedition of Oñate really left Mexico City in 1596. And although he doubtlessly kept up his communications with Old Mexico, and was followed by other companies of intended colonists, we can only infer, with safety, that whenever the inscription on the Concepcion mass was made, it was desired to commemorate the fact that the mass was at that time supposed to have been already known in the year 1600.

According to Manuel Orozco y Berra,[1] Don Juan de Oñate and his companions in New Mexico were so eager in their search for precious metals, that they neglected to construct a fort at San Gabriel, or to secure grain for the colonising force. Famine set in; and the colonists, disappointed in their expectations, seized the opportunity of Don Juan's absence on an exploring expedition to return to Santa Barbara in 1601. On his return to San Gabriel, Don Juan declared the absentees to be traitors, and condemned them to death: he set off towards Santa Barbara to give effect to his sentence, and reached there at the beginning of January 1602.

It is clear that about the year 1600 there was an extraordinary amount of traffic in the immediate neighbourhood of the masses of iron belonging to the Huejuquilla group.

Another account of the landmark.

Although, in his description of Oñate's expedition, Geronimo de Zarate Salmeron makes no reference to the iron-landmark, a search through his journal brings to light a statement, by which we are able to establish that neither a Chupaderos mass nor that of Concepcion is the one referred to in the above account. After mentioning other evidence that Old Mexico had been peopled in ancient times from the North, Zarate Salmeron proceeds as follows:[2]—

"There is also an old tradition among the Indians that a lump of metallic iron, which is three leagues distant from Santa Barbola (*sic*), and half a league away from the road along which the carts pass when going to New Mexico, is a memorial of the coming of the Mexicans to people this country (Old Mexico); and that they halted near there, and that the idol which used to speak with them told them that it would tarry at the place as a memorial. The iron must weigh upwards of 800 quintals, and they say

[1] *Apuntes para la Historia de la Geografía en México.* México, 1881, p. 153.

[2] *Documentos para la Historia de México.* Tercera Serie. México, 1856, vol. 1. pp. 47-8.

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that a deity, in the form of an Indian woman, aged and wrinkled, used to draw it along. How remarkably strong the Indian old woman must have been! It is an object which all who pass along this road go and look at as a curiosity. A blacksmith of Santa Barbola (*sic*) severed a bit from one side; and others, not believing it to be an object which could have been moved and dragged from a distance, but suspecting it to be (the outcrop of) a mine of native iron, made an excavation beneath it: on the removal of the earth by which it was supported, the mass turned over on one side, and it is in that position at the present day."

This statement evidently refers to the mass mentioned in the History of Philip II. by Luis Cabrera de Cordoba. The two statements differ in character, and must have been made independently of each other, though recording the same Indian tradition: for the latter historian died in 1623,[1] and apparently was never in Mexico, while Geronimo de Zarate Salmeron's journal, preserved in Mexico City, was not ordered to be published till 1629.

To fix the position of the iron-landmark at the end of the sixteenth century we thus have two statements:—1st, that the site was on the route taken by Oñate to New Mexico, and in latitude 27½° north; 2nd, that the mass was three leagues from Santa Barbola, and half a league from the highway to New Mexico.

Santa Barbola is identical with Santa Barbara.

In the description of the journey of Espejo, published in 1586, it is stated that when the soldiers returned to El Valle de San Bartolomé, Espejo was at *the mines of Santa Barbola* (*sic*): in a later sentence the name is printed as *Barbora*. Geronimo de Zarate Salmeron spells the word as *Barbola*, but he was familiar with the above work and might have followed its spelling. Davis,[2] who had access to various old official documents, states that Espejo was at the mines of *Santa Barbara*; a place of that name is situated eight leagues south of Hidalgo del Parral.

At first it appeared that the Santa Barbola of 1582 must be quite distinct from the Santa Barbara of the present day, for according to J. A. de Escudero,[3] the mineral veins at Santa Barbara were not discovered till 1747: as shown below, the date is probably a misprint for 1547.

That the mines at Santa Barbara were worked by the Spaniards in the

[1] *Grande Encyclop.* Paris, 1889, vol. 8, p. 648.

[2] *The Spanish Conquest of New Mexico.* By W. W. H. Davis. Doylestown, Pa., 1869, p. 239.

[3] *Noticias Estadisticas del Estado de Chihuahua.* México, 1834, p. 129.

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sixteenth century, and were antecedent to those of Parral itself, is shown by the following:[1]—

"The mining place of Santa Barbara is in the Division of Hidalgo, and south-east of that town: it was discovered in the year 1547. Most of the mines have been abandoned since time immemorial, but they must have been very rich, for the veins have been worked out to their full extent." "The town of Santa Barbara, in the neighbourhood of Hidalgo (del Parral), was the first part of the State of Chihuahua to be peopled by the Spaniards. The formation of a town was begun in 1556, in consequence of the discovery of the mineral veins, and in the year 1600 there were seven thousand inhabitants employed in the working of the gold mines. The diminution of the yield at Santa Barbara, and the new discoveries made at Parral, had for result a transference of population to the latter town, and afterwards further north, in consequence of the discovery of Santa Eulalia, Cieneguilla, and later still Cusihuiriachic." The identity of Santa Barbara and Santa Barbola is confirmed by the following statement:[2]— "For the State of New Biscay, Lionnel Waffer (*sic*) mentions some silver mines, and gives Durango as the principal town: its other towns are called Barros, Sta. Barbara or Barbola Endehe, and San Juan." Lionel Wafer's voyages were made between 1677 and 1688: a French translation of the account of his travels was published at Paris in 1706 under the title *Les Voyages de Lionnel de Waffer:* neither in the original nor in the French version does the form Barbola appear to have been used. Endehe or Ende is doubtless a separate place, and identical with the present Indé, 30 leagues S.E. of Sta. Barbara.

The old landmark is identical with the mass now at San Gregorio.

Not one of the four large masses, which still exist in the south of the State of Chihuahua, is at present situated within three leagues of the mines of Santa Barbara. The two at Chupaderos are far away from both the road to New Mexico and the mines; it will be established later that the Concepcion mass was transported in 1780 from a place likewise far distant from any mining locality. The mass nearest to the place specified is that now at San Gregorio, a hacienda eight miles north-west of El Valle de San Bartolomé, and situated between that town and Parral: the hacienda is a league distant from the Parral road.

As shown below, its history, so far as known to us, is not inconsistent

[1] *Bol. Soc. Mex. de Geog. y Estad.* México, primera época, 1857, vol. 5, pp. 246, 272.

[2] *Algemeine Historie der Reisen zu Wasser und zu Lande.* Leipzig, bei Arkstee und Merkus, 1755, vol. 13, pp. 508, 686.

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with the view that the mass is the old landmark: no stress can be laid on the difference between the estimated weights (800 and 250 quintals). Yet the present location of the mass does not accord at all precisely with the specification given by Geronimo de Zarate Salmeron.

Santa Barbara is about ten leagues distant, in direct line, both from the hacienda of San Gregorio and from the highway (now in use and which has been in use for centuries) to New Mexico. A cart-road, however, now goes through Cerro Gordo, Torreon, Bocas, Cuevas and Hidalgo del Parral, and passes within three leagues of Santa Barbara; if this road existed in the year 1600, and is the one referred to by Geronimo de Zarate Salmeron, the mass must have since been transported many leagues by the Spaniards. On the other hand, if the road through El Valle de San Bartolomé is signified, the distance of three leagues from Santa Barbara is much too small.

The large "Durango mass" mentioned by Humboldt.

After the large iron-landmark had been neglected and almost forgotten, outside its immediate neighbourhood, for two centuries, public attention was directed to the existence of such a mass by Humboldt, in his classic work on New Spain: unfortunately, owing to his ignorance of the previous history of the iron and his misunderstanding of the statement as to its situation in Mexico, his reference to it was of such a character that it has led to an incredible amount of controversy and vain searching of the country.

In describing the city of Durango, he says:[1]—"It is in the neighbourhood of (the city of) Durango that is seen, isolated in the plain, that enormous mass of malleable nickel-iron, which is identical in composition with the meteorite which fell near Agram, in Hungary, in 1751. Don Fausto d'Elhuyar, Director of the Royal School of Mines of Mexico, gave me some fragments which I have presented to various European collections; and Vauquelin and Klaproth have published analyses of them. I am assured that this Durango mass weighs nearly 19,000 kilograms, which is 4,000 more than that of the mass discovered at Otumpa, in Tucuman (South America), by Rubin de Celis."

Various opinions as to the "Durango mass" of Humboldt.

Chladni (1819)[2] expressed the opinion that Humboldt had been wrongly

[1] *Essai cit.*, Paris, 1811, vol. 1, p. 293.

[2] *Ueber Feuer-Meteore*, Wien, 1819, p. 337.

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informed, and that the big mass was identical with the comparatively small one at Charcas (578 kilograms): this opinion was based on the negative evidence that Sonneschmid[1] in his Review of Mexican Mining, published in 1804, had made no mention of a large mass near Durango. This line of argument is untenable, for Chladni, at least; since he himself acknowledges the existence of the Sierra Blanca masses, which are themselves unnoticed in Sonneschmid's work: the fact is that Sonneschmid was only describing the mineral districts which he had himself visited, and he incidentally mentioned the masses of meteoric iron at Charcas and Zacatecas, because they were in the districts being described: as none of the mines in the neighbourhood of El Valle were under discussion by him, we might have expected that the masses of meteoric iron belonging to that part of Mexico would be unmentioned, whether their existence was known to him or not.

Hardy (1829), as stated below, thought that the mass was possibly identical with that of San Gregorio.

Ramirez (1843)[2] denied the existence of the large mass near Durango, and expressed the view that the fragments given to Humboldt had been taken from the Zacatecas mass.

Partsch[3] (1843) and Boguslawski[4] (1854) thought they had been brought from Toluca.

Weidner[5] (1858) also denied the existence of the large mass, and expressed the opinion that the fragments were either from the Labor de Guadalupe, near Durango, or from one of the large masses "at Rio Florido and Concepcion."

Humboldt, on the other hand, still declined to regard the mass as mythical: he assured Burkart (1856) that D'Elhuyar had talked to him about the mass, not once, but a hundred times![6] Burkart, thereupon, again made inquiry in Mexico, and heard (1857)[7] that a large meteorite really existed in the plain east of the city of Durango; and he was promised further information. This never arrived, and Burkart was informed by other persons that the mass was not to be

[1] *Mineralogische Beschreibung der vorzüglichsten Bergwerks-Reviere von Mexico oder Neuspanien*, Schleiz, 1804.

[2] *El Museo Mexicano ó Miscelanea Pintoresca de Amenidades Curiosas e Instructivas*, México, 1843-5, vol. 1, p. 29.

[3] *Die Meteoriten zu Wien*, 1843, p. 112.

[4] *Pogg. Ann., Ergänzungsband* 4, 1854, p. 411.

[5] *Bol. Soc. Mex. de Geog. y Estad.* Primera época, México, 1858, vol. 6, p. 61.

[6] *Neues Jahrbuch für Mineralogie*, 1856, p. 285.

[7] *Ibid.*, 1857, p. 53.

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found :[1] being still not convinced that no such mass existed near the city, he suggested that the Breña—a volcanic group between Durango City and Nombre de Dios—should be closely searched. Later still (1866),[2] owing to the continued failure of the searches, he reluctantly inferred that Humboldt must have intended to indicate one of the Chihuahua masses, and that he had only mentioned Durango because there was no other big town in the neighbourhood.

Tarayre,[3] after a visit to Durango, thus reported (1867) :—"Several masses of meteoric iron are met with : one of them, weighing about 200 kilograms, is used as an anvil by a blacksmith of Durango. It was found in the neighbourhood of the city. There has been much talk of the large meteoric mass, *three-fourths buried in the plain*, not far from the hill called Mercado. Humboldt estimated the weight as 19,000 kilograms, according to information furnished to him at Mexico. The mass has never been dug out so as to permit of an exact estimation of the weight, and it appears there may be some exaggeration in the above figure."

This statement, which seemed by its additional detail to confirm the existence of the mass, caused Burkart to resume his inquiries once more; and, as a result, in 1871, he reported[4] that one person had been unable to find it, that another hinted that he knew where it was but was keeping the place a secret, while a third expressed doubts as to its existence; in the end Burkart died without arriving at the true solution of the problem.

The Huejuquilla masses were at one time known as "Durango iron."

And yet the explanation is an extremely simple one. At the time when Humboldt was in Mexico, and for many years afterwards, till the rebellion against Spain, the Province of Durango or New Biscay included, not only the present State of Durango, but also those of Chihuahua and Coahuila: hence the whole Huejuquilla group was then in the *Province* of Durango; and before other masses had been found in the same Province, they could very appropriately be termed "Durango iron." Humboldt merely misunderstood the intended meaning of the term Durango, taking it to be the City instead of the Province.

That this is the true explanation there cannot be a shadow of a doubt. The structure of Humboldt's initial sentence clearly indicates that he was referring to some large mass of which the existence at the time of writing

[1] *Neues Jahrbuch für Mineralogie*, 1858, p. 773.

[2] *Ibid.*, 1866, p. 408.

[3] *Archives de la Commission Scientifique du Mexique*, 1867, vol. 3, p. 270.

[4] *Neues Jahrbuch für Mineralogie*, 1871, p. 851.

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was a matter of common knowledge: though, indeed, the suggestion of common knowledge may be wholly based on the publication of the analysis of his fragment by Klaproth in 1807.

But the "iron-landmark," in the Province of Durango, near latitude 27½°, had been then known for more than two centuries: since 1780 the Concepcion mass, also in the Province of Durango and situated "upon a level plain, twenty miles from any mountain," had been lying close to a line of traffic, along which, at the time when Humboldt was in Mexico (1803), thousands of mules were passing every week: an account of the discovery of large masses of iron at Sierra Blanca, in the same Province, had been published in Mexico City in 1784: a notice of the finding of a mass at La Plata, also in the same Province, had been similarly published in 1802. At the time of Humboldt's visit, no Mexican Province was comparable with Durango for the number of its isolated iron-masses, and the fact must have been perfectly well known to the mineralogists in Mexico City. Indeed, Del Rio, Professor at the Royal School of Mines at Mexico, in his Mineralogical Tables[1] (1804) cites the *Province of Durango* as a locality for native iron; and in the Second Part of his Mineralogy[2] (1805), under Native Iron, he mentions "the mass weighing 800 quintals which Rubin de Celis found on a vast plain of South America, and *those* which are found in the Province of Durango under similar circumstances." He gives no more precise information than the above. This text-book Humboldt was familar with: indeed, his name appears on the title-page of the Second Part, for he contributed to that Part an essay on the geology of the country: in his own description of New Spain,[3] too, he expressed his indebtedness for mineralogical information to the works of both Sonneschmid and Del Rio. It is thus impossible to escape the conclusion that the large Durango mass, about which Humboldt had often conversed with D'Elhuyar, was the one which had been lying near the road to Chihuahua and in the Province of Durango or New Biscay, ever since the arrival of the Spaniards in Mexico.

And at the time when Humboldt's statement was published, his verbal misapprehension was doubtless considered by the Mexican mineralogists to be of so trivial a character that correction by them was unnecessary: as we shall see later, Hardy, who was the first to note the presence of a mass at San Gregorio itself, suggested its identity with Humboldt's Durango mass. It was not till many years after Humboldt's visit that the assignation

[1] *Tablas Mineralogicas;* México, 1804, p. 57.
[2] *Elementos de Orictognosia*, Segunda Parte, México, 1805, p. 40.
[3] *Essai cit.*, vol. i, *Introduction géographique*, p. L.

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of the El Valle and Huejuquilla district to the State of Chihuahua rendered the term "Durango iron" quite inappropriate, and thus made Humboldt's statement quite inexplicable even to those living in Mexico.

[In the Index of the *Gazetas de México* for 1793, there is a reference to a notice on page 59 '*De acero de peso de 2,000 arrobas.*' A complete copy of the Gazette for that year is preserved neither in London nor Paris. The weight 2,000 arrobas (or 500 quintals) approximates to that mentioned by Humboldt.]

No stress can be laid on the discrepancy between the estimated weight of the "Durango" mass (19 tons) and the latest estimate of that of the San Gregorio mass (11 tons). Estimates of the weights of such masses depend very much on the estimator: the iron-landmark was supposed three centuries ago to weigh about 40 tons (800 quintals); the San Gregorio mass was stated by Butcher to weigh about 5 tons. The larger of the two masses at Chupaderos weighs, according to one recent estimate 15½ tons, according to another 82 tons.

The labels of those "Durango" fragments which have been given to European collections by Humboldt may thus be safely altered to indicate that the fragments belong to the Huejuquilla group: if taken from the big mass mentioned by him, they are fragments of that of San Gregorio; but if they were given to him merely as "Durango iron," they may belong to any of the masses of the Huejuquilla group known at that date.

Humboldt only referred to the more important masses previously recorded.

We may incidentally remark that the only Mexican masses of iron mentioned by Humboldt[1] are all remarkable as being either individually large (Durango, Zacatecas, Charcas), or as forming a numerous group (Toluca): that if we take Durango to indicate a "Province of Durango" mass, all of them are included in those previously mentioned by Del Rio and Sonneschmid; and that of the remainder mentioned by one or other of those two writers, but omitted by him (namely, Misteca and Guangoche), almost nothing was at that time known."

It is obvious that Humboldt's remarks were made under the impression that he was merely making mention of masses which had already attracted much notice in Mexico itself.

Supposed meteoric origin of the hill called Mercado.

Humboldt's misinterpretation of the term *Durango iron*, led to a wild

[1] *Essai cit.*, vol. 1, p. 293; vol. 2, p. 582.

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misinterpretation of Humboldt's own statement; for, as no mass of meteoric iron was known in Durango City to be lying on the neighbouring plain, it came to be a matter of common belief that Humboldt was referring to the Cerro Mercado, a hill close at hand, and was expressing the opinion that the Mercado is nothing else but an immense meteorite! In 1846 Ruxton passed through Durango City, and the confusion at that date is illustrated by the following remarks:[1]—

"Durango is celebrated for the enormous mass of malleable iron which rises isolated in the plain about three miles from the town. This rock is supposed to be a meteorite, as its composition and physical character are identical with certain meteorites which fell in 1751 in some part of Hungary, and analogous to the general character of others of the same nature, of which the meteoric origin is equally certain and authenticated. It contains 75 per cent. of pure iron, according to the analysis of a Mexican chemist; and some specimens, which Humboldt procured, were analysed by the celebrated Klaproth with, I believe, the same result."

The general prevalence of this belief is sufficiently shown by the fact that in 1843 Ramirez,[2] and in 1858 Weidner,[3] published memoirs relative to the Mercado, in which they deemed it necessary to disprove in an elaborate way the meteoritic theory of its origin, supposed to have been brought forward by Humboldt.

It need scarcely be said that Humboldt never expressed such an opinion: in his work on New Spain, it is true, he mentioned the hill called Mercado and the Mexican meteoric irons almost simultaneously, but merely because he was describing the modes of occurrence of iron in Mexico, and the Mercado was known by the Mexican mineralogists to be an enormous mass of iron-ore. In fact, Humboldt himself never travelled so far north as Durango, and could only give such information about the hill as had been supplied to him by others.

Hardy.

After Humboldt's reference, the next mention of the mass was made by Hardy,[4] who travelled through the neighbourhood in 1827: it is the first record of the presence of the mass at San Gregorio. He says:—

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[1] *Lib. cit.*, p. 86.

[2] *El Museo Mexicano ó Miscelanea Pintoresca de Amenidades Curiosas e Instructivos*, México, 1843-5, vol. 1, p. 28.

[3] *Bol. Soc. Mex. de Geog. y Estad.* Primera época, 1858, vol. 6, p. 59; and *Neues Jahrb. f. Min.*, 1858, p. 769.

[4] *Travels in the Interior of Mexico in* 1825-8. By R. W. H. Hardy. London, 1829, p. 481.

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"From the hacienda of Santa Cruz to the Real del Parral the distance is 12 leagues. Nine leagues on the same road is the town of San Gregorio, where there is an enormous mass of malleable iron and nickel, perhaps the meteorite which Mr. Humboldt describes as being near the town of Durango. Real del Parral had formerly a population of fifty or sixty thousand souls, and was very celebrated in its day, which has now gone by. Many attempts have been made to melt down this mass of iron, but without success. An Italian imagined that by heating one side of it he should be able to cut off as much of the metal as he wanted. Accordingly he piled on the part where he intended to commence his operations an immense quantity of wood to which he set fire, and by dint of united blast of five or six forge-bellows he succeeded in giving it a red heat, which indeed was so insupportable that to his astonishment he could not come near it. However, I am told that, by applying a wall of thick boards before him, he succeeded in obtaining three pounds of iron; which three pounds cost him 130 dollars, and they were not worth four."

Hardy left the hacienda of Rio Parral (not Real del Parral) at 5 a.m., reached Santa Cruz at 8 a.m., and was in El Valle de San Bartolomé at 8 p.m. the same day: there is an element of doubt as to whether he can have had time to go to the hacienda to see the mass, for it is some distance from the road to El Valle: he gives no description of the mass or of its position, and fails to mention the inscription upon it, which, according to one account, is dated 1821.

The population of El Valle was then 28,000.

Bartlett.

Bartlett heard of the existence of the San Gregorio mass in 1852, but he did not journey to see it.[1]

Butcher and Lawrence Smith.

Dr. Butcher detached some fragments and sent them to Professor Lawrence Smith,[2] who published (1871) a sketch of the mass, and said:—"Upon one part of its surface 1821 is cut with a chisel, and above this date the following inscription in Spanish, '*Only God in his might can destroy this iron, for none on earth is able to divide it.*' It lies within the enclosure of a hacienda, having been hauled to the ranch many years ago by the Spaniards, who thought that it could be made use of as iron for farming

[1] *Lib. cit.*, vol. 2, p. 458.

[2] *Amer. Jour. Sc.*, 1871, ser. 3, vol. 2, p. 336.

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utensils. It is said to have fallen quite near its present site, and from its huge bulk and weight, which is calculated to be about 5 tons, it could not have been transported very far. Nothing more is known of its history."

The place designated throughout as El Para by Lawrence Smith is really Parral (or Hidalgo del Parral).

Parras.

Burkart[1] (1871) quotes an account of the mass communicated to him in a letter by Don Anastasio Parras (not Porras) of El Valle de San Bartolomé: mention is made of the attempt to reduce the mass, and also of the above inscription, but the inscribed date is given as 1828, a date subsequent to that of Hardy's journey. Parras further says that the mass must have fallen 7½ leagues from the hacienda of San Gregorio; that no one knew at what time it had fallen; but that it was certainly long ago, for since the beginning of the eighteenth century, the mass of iron, laid bare by the rain, had been used as a boundary-mark of the hacienda of San Gregorio and the landed property of the town of El Valle. Parras states that the mass was moved to the square of the hacienda about fifty years before the date of his letter.

As Parras says that the mass was unknown till its discovery near the boundary, there must be an error of printing in his statement of the distance of removal, for the hacienda is only eight miles from El Valle itself: probably 1½, not 7½, was written by him.

Even if the previous history had been actually lost, as Parras supposed, we might have safely inferred that the mass could not have been lying near so important a town as El Valle for one or two centuries without being discovered, and that the mass had been known to former inhabitants of the town before the occasion when it was again laid bare by the rain.

We shall see that exactly the same account of revelation by a shower of rain, within a short distance from the hacienda, was given for the Concepcion mass, in 1871, by the actual owner, and yet it is now established that the mass had been removed from near Huejuquilla in 1780: it is remarkable, too, that there is almost exactly the same tradition relative to the attempt to cut large pieces from the two masses.

Castillo.

Castillo (1889)[2] says:—"It fell at the place called El Morito, 4½

[1] *Neues Jahrbuch für Mineralogie*, 1871, p. 853.

[2] *Cat. Des. cit.*, p. 7.

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kilometres from the hacienda of San Gregorio, and the then proprietor (? 1600), Raphael de Pastrana, had it transported to the square of the hacienda, where it still lies."

Knotts.

In a letter sent in answer to my inquiries, Mr. J. D. Knotts of Parral states that, according to local tradition, the mass was moved, some 130 or 140 years ago, to the hacienda of San Gregorio from El Morito, about two leagues distant in an easterly direction. About four or five years since it was moved by the present owner from the centre to the corner of the hacienda, about 70 feet, to form part of the house: 50 men with levers were employed in the latter removal.

B. The Concepcion mass.

The following are the accounts which have been published at various times relative to the mass now at the hacienda of Concepcion:—

Connolly.

Henry Connolly,[1] Governor of New Mexico, with whom General Carleton had been discussing the meteoric iron of Tucson, gave him the following information:—"In the State of Chihuahua, and at the hacienda of Don Juan Nepumocena Urquida (*sic*), say 180 miles south of the city of Chihuahua, and directly on the road from that city to Mexico, and directly among the houses of the above-named hacienda, on the left hand side of the road going to the city of Mexico, and within from 30 to 50 yards of the main road, is what is supposed to be a meteorite. I saw it nearly every year for 20 years, the last time in 1846. It is a large mass of solid iron, standing like a post in the earth, from which it projects vertically about 4 feet. Its diameter at the surface of the earth is from 2 to 3 feet. It diminishes in size a little from the earth to its apex, which is irregularly rounded. The part above the ground would weigh a ton or more."

Lawrence Smith and Weidner.

Probably this is the mass which had been previously referred to by Lawrence Smith in 1854-5:[2]

[1] *Smithsonian Report for* 1865, p. 124.

[2] *Amer. Jour. Sc.*, 1855, ser. 2, vol. 19, p. 160.

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"Weidner, of the mines of Freiberg, states that near the south-western border of the Bolson de Mapimi, on the route to the mines of Parral, there is a meteorite near the road of not less than a ton in weight.

According to Manuel Orozco y Berra,[1] Weidner was at Parral, in the year 1850, as engineer to the Prieta and Tajo Mining Company, and published plans of the mines; in the same year he prepared a description of the route from Parral to Durango and Monterey (*Itinerario y carta geognóstica del camino del Parral para Durango y Monterey, formada en* 1850 *por Federico Weidner*). The statement quoted by Smith is probably taken from the latter work, a copy of which is inaccessible to me.

Simson.

Robert Simson,[2] writing about the year 1866, but quoting from memoranda made at some previous time, says:—"About halfway between El Valle and Parral, on a bend of the Rio Florido, at a place called Concepcion, is a most splendid specimen of meteoric iron. It is 4 feet above ground, and almost pure in quality. It is from two to three feet one way, by probably two to five feet the other, very regular in shape, and where worn by the rubbing of hands, &c. of passers-by is bright, and to all appearance, is nearly pure metal. The steel hatchet cuts into it easily, but with our means at hand we found it impossible to detach any part of it. It stood at the corner of the house, apparently to guard it from collisions of wagons and the like. The majordomo said this meteorite had, as he had heard, fallen from the heavens, and had been brought from a distance, from a place where other specimens also existed. Such we found to be the prevailing account of this mass among the people of the place. I would state that from La Concepcion to the Rio Grande there is an excellent road leading through Saltillo and Monterey, and save in respect to its weight, there would be no difficulty in conveying this meteorite (to the United States). The common carts of the country, with solid wooden wheels, could well convey it."

There is an error in the above statement of locality, for the hacienda of Concepcion does not lie between El Valle and Parral; indeed, El Valle itself is halfway between Parral and the hacienda of Concepcion: as discussed above, there is a large mass at San Gregorio between El Valle and Parral, but being distant from the main road it does not attract as much notice from travellers; Simson's letter is of special importance as a record

[1] *Apuntes para la historia de la Geografía en México.* México, 1881, p. 364.

[2] *Smithsonian Report for* 1867, p. 472.

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of the tradition of the removal from a distant place, where other masses were still lying, and of the excellence of the roads in its neighbourhood.

Bartlett and Urquidi.

Bartlett,[1] who was travelling in 1852 by way of Huejuquilla and Rio Florido, made an excursion from his direct route to view the mass: he says:—

"We came to a small stream, where, encompassed in a grove of cotton-woods, lay the pretty village (Concepcion) to which we were destined. On our arrival we stopped under the shade of some large trees, and dismounting at once discovered the object of our search, about 50 yards distant, at the corner of a large building. This was the residence of Don Juan Urquida (*i.e.* Urquidi), the proprietor of the hacienda and large estates adjoining, and formerly Governor of the State. That no time might be lost, Dr. Webb immediately set to work with his hammer and cold chisels to cut off some pieces from the large mass of iron before us. This he found to be an undertaking of great labour, in consequence of the extreme tenacity and hardness of the mass. After an hour's work with a man to assist him, he succeeded in cutting off 3 or 4 small pieces, which did not altogether weigh an ounce, and were barely sufficient for an analysis. Five chisels having been broken, the doctor had to desist from his labours, much to our regret, as we were desirous to obtain some specimens for cabinets. While this was going on I took a couple of sketches of the mass showing opposite sides, and also took measurements; but the form was so irregular that these measurements can only aid in conveying an idea approximately of its bulk. Its greatest height is 46 inches; greatest width 37 inches; circumference in thickest part 8 feet 3 inches. Its estimated weight, according to Señor Urquida, is 3,853 lbs. While we were at work, Señor Urquida the younger, the brother of Don Juan, came out. He said it was originally found about 300 *varas* (270 yards) from its present location, and had been moved at different periods by the people of the hacienda to the place where it now stands. It was brought hither with the design of putting it in a blacksmith's shop to be used as an anvil, although it had never been so employed. An attempt was made to reduce it, by building a large fire round it and heating it to a white heat. But so intense was the heat from so large a mass that the workmen could not approach it, and all their labour was lost. The expense of this operation was more than 100

[1] *Lib. cit.*, vol. 2, p. 457.

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dollars, and resulted in obtaining a piece of the metal large enough to work into a pair of spurs."

Urquidi.

An account of the Concepcion mass, published by Francisco de P. de Urquidi,[1] places on record as much as was known, in August 1871, at the hacienda itself.

The following extracts relate to the history:—

"The place at which the mass is now located is not that which was first known. By tradition we know, though in an indirect and inexact way, that at a time very remote it was at a point distant more than 1,000 *varas* from the *casa principal* of the hacienda: according to the same tradition, the mass was transported to the neighbourhood of the *casa principal* and placed in front of the church door. There it was known by persons who have not yet been long dead. At the beginning of this century, a manager of the hacienda sought to profit by transporting it to a forge to be used as an anvil: it was at the door of that workshop when the present owners (*i.e.* Urquidi) of the hacienda first knew it: from there they had it moved to the spot where it now is, at a corner of the *casa principal*, and had it placed on a small pedestal of masonry. Many little pieces have been hacked from the mass; from some of them have been forged various articles of smithy-work, others have been taken away as specimens. In the same district there are three other masses quite similar in their material: one 12 leagues to the north-west, at a hacienda called San Gregorio, and the other two at 25 or 30 leagues to the north-east, at 160 paces from each other, in a part of the desert of the Bolson de Mapimi, near a place known as Chupaderos, on a hill outside the mountain-ridge. No other mass of this kind is known to exist in all this extensive territory, unless it be the Tucson iron, which, along with that of Descubridora, may possibly have fallen from the same meteor."

Burkart,[2] though apparently quoting from what is virtually the same account, mentions one or two points not in the above paper: they may have been given as marginal notes on a copy sent to him, along with a fragment of the mass, by Urquidi: he says that according to report the mass had been laid bare in the copse, about 800 *varas* from its present position, in a water-course produced by a violent shower; and that the mass was still near the smithy in 1828.

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[1] *Bol. de la Soc. Mexicana de Geog. y Estad.* Segunda época, 1871, vol. 3, p. 275.

[2] *Neues Jahrbuch für Mineralogie*, 1871, pp. 852-3.

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Castillo and Urquidi.

According to Castillo (1889),[1] F. Urquidi states on the authority of a letter of his uncle, A. Urquidi, that the mass was transported to Concepcion from the Sierra de las Adargas, near Huexuquilla (*sic*) on 29th April, 1780. Apparently Urquidi must have discovered the letter since the publication of his paper in 1871: the latest information is thus in much closer agreement with the statement made by the majordomo to Simson before the year 1866.

Sierra de las Adargas is not given on the available maps, but Don José de la L. Soto, the owner of the hacienda of Chupaderos, informs me that the name is applied to a hill (*pequeña montana*) eight or nine leagues south of the town of Jimenez (Huejuquilla), and within that jurisdiction.

C. The Rio Florido mass.

The town of Rio Florido is at the junction of the roads which lead from Huejuquilla and El Valle de San Bartolomé respectively to Durango City. Hardy says:[2]—"I left El Valle at 7 a.m. and arrived at the hacienda of Concepcion at eleven. This I passed, and reached the hacienda of Rio Florido at 3 p.m. The house is a palace, with a long colonnade in front. It was built by Father Juan Ceréra, a Spanish priest, during whose lifetime the hacienda was celebrated as one of the richest in Mexico."

The mass said to have been at the hacienda of Rio Florido appears to be really identical with that of Concepcion.

The information relative to the mass is small. Weidner[3] first referred to it incidentally in 1858:—"I have actually seen, on the very edge of the road from Durango to Chihuahua, at the haciendas of Rio Florido and Concepcion, two masses of malleable iron which appear to be meteorites." Castillo[4] (1889) says:—"In 1866, Federico Weidner, when giving me some information relative to the meteorites of the Northern States of Mexico, spoke to me of a mass which was at the hacienda of Rio Florido, on the old highway from Mexico to Chihuahua. The mass was about half as large as that at the hacienda of Concepcion, flatter than the latter, but presenting the same characters. As Weidner assured me that he had hacked some fragments from it, I mention the mass here: I have been

[1] *Cat. Des. cit.*, p. 7.
[2] *Lib. cit.*, p. 483.
[3] *Bol. Soc. Mex. de Geog. y Estad.* Primera época, 1858, vol. 6, p. 61.
[4] *Cat. Des. cit.*, p. 9.

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unable to find any other description of it, and during my visit to the hacienda of Rio Florido itself, in March last (1889), I could neither find the mass, nor get any information relative to it." In answer to inquiries from Burkart[1], made through Stahlknecht of Durango, Weidner wrote, on 10th September, 1870:—"During a journey to Chihuahua, I saw two masses, one at the hacienda la Florida (*sic*), the other at the hacienda Concepcion. Without delaying the caravan I was able to hammer off a small piece of the *former* meteorite, and of the external character of this mass I remember the following:—It has no predominant form, and could at most be compared with a heavy club. The thinner part is buried deep in the earth, the free, visible, broader part is about a metre high and 40 centimetres thick. Its surface is rounded and kidney-shaped; everywhere smooth, and in parts bright, like polished steel, although covered here and there with pores. An outer rind or black crust, differing from the interior, is not observable. In hardness it seemed to be equal to cast iron; its section was fairly smooth: on its fractured parts it showed a hackly appearance, like that of silver. From its place of preservation and its position, one may infer that it has been hauled thither by the landlord from somewhere in the neighbourhood, and has been sunk in the earth close to the corner of the house as a corner-stone."

In 1866, Whitney[2] remarked:—"Dr. J. B. Trask saw in August 1849 a large mass of meteoric iron at the village of Rio Florida (*sic*), partly buried in the ground at the corner of the *plaza*. This may perhaps be the same mass mentioned by Mr. Bartlett as existing at the hacienda of Concepcion, on the road from Chihuahua to Rio Florida. Dr. Trask, however, has a distinct recollection that the mass he saw was at the village of Rio Florida, and not at the hacienda."

Abner Woodworth,[3] in 1866, wrote to the Secretary of the Smithsonian Institution:—"On the 7th of March, 1848, I left Paral (*sic*), a town situated on the river Allende, State of Chihuahua, and travelling some 25 miles, course 15° east of south, passed a lump of solid malleable iron, shape or figure resembling two inverted saucers, one-third or more buried in the ground, supposed to weigh 5 or 6 thousand pounds. The blacksmith at Rio Florido cuts off pieces with his cold chisel for horseshoes. It lies upon a level plain, 20 miles from any mountain."

Comparison of the statements.

The statements made by Trask and Woodworth are useful as suggesting

[1] *Neues Jahrbuch für Mineralogie*, 1871, p. 854.
[2] *Proc. Calif. Ac. Nat. Sc.*, 1866, vol. 3, p. 241.
[3] *Smithsonian Report* for 1867, p. 472.

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an interpretation which may be given to Weidner's report. Woodworth only mentions a single mass: the San Gregorio mass being a league from the road escaped his notice, but as is proved by the descriptions of Simson and Bartlett, the Concepcion mass was so conspicuous that it continually attracted the attention of passers-by and was hacked by them at discretion. Woodworth is not likely to have missed such a specimen, and have observed one of which almost nothing is known, and which is said to have been only half the size of the Concepcion mass. Simson himself refers to the stream which passes close by Concepcion as a bend of the Rio Florido: as a matter of fact, two different streams pass by the villages of Concepcion and Rio Florido, and unite about 12 miles away. Such a fact would be unknown to an ordinary traveller, whose journey along an excellent road could necessitate no reference to a detailed local map, even if such a map had then existed: the stream now called Rio Florido is the more important one, and the course of the road from the village of Rio Florido to Huejuquilla is determined by it.

There is a similar misapprehension, as regards Rio Allende, on the part of Woodworth; for Parral is not on the stream passing through Allende (El Valle), but on another stream (Rio Parral) which joins the Rio Conchos or Florido at Santa Rosalia, more than sixty miles distant from Parral.

Taking these things and the stated distance from Parral into consideration, and remembering that for many years the Concepcion mass had lain close to the smithy, it cannot be doubted that Woodworth's 'blacksmith at Rio Florido' was really the 'blacksmith at Concepcion, on a branch of the Rio Florido.' If this be granted, Trask's statement also falls to the ground: his distinct recollection that "the mass he saw was at the village of Rio Florida (*sic*) and not at the hacienda," would merely imply that the mass was outside the hacienda (of Concepcion): indeed, Bartlett's description indicates that the hacienda and village are virtually identical in location, and Connolly says that the mass was directly among the houses of the hacienda up to 1846 at least.

The statement of Weidner now becomes more capable of interpretation: his description of the position and characters of the mass at "Rio Florido" agrees so well with those given by Simson and Bartlett for the Concepcion mass, that it is impossible to come to any other conclusion than that the two masses are identical: and further, that Weidner's second and larger mass was not that of Concepcion, as stated by him, but the one at San Gregorio. Of the existence of the latter, though the mass is not directly referred to, he can scarcely have been ignorant: for, as already mentioned, he was employed for some time in the neighbourhood as engineer at

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Parral, and his familiarity with the region is established by the fact that he had constructed a geological chart of the road from the mines of Parral (through El Valle, Concepcion, Rio Florido, Cerro Gordo) to Durango and Monterey.

As stated above, Lawrence Smith[1] (1854-5) says:—"Mr. Weidner, of the mines of Freiberg, states that near the south-western edge of the Bolson de Mapimi, on the route to the mines of Parral, there is a meteorite near the road of not less than a ton in weight."

The search for a published authority for this statement of Lawrence Smith has been fruitless; as suggested above, it may have been quoted from the *Itinerario* of 1850: the statement is of particular interest as showing that before 1854 only a single mass, apparently that of Concepcion, had been specially called attention to by Weidner.

Weidner states that he broke off the fragments at Rio Florido "without delaying the caravan": his information may thus have been acquired very hurriedly and be inexact, though it is still difficult to explain away his statement that *both* masses were close to the edge of the road.

If any further confirmation be required of the possibility of the confusion of the two villages of Concepcion and Rio Florido, by reason of the small stream passing through the former being a tributary of the larger one passing through the latter, it is given by the following extract from a memoir by Pedro Garcia Conde relative to the State of Chihuahua (1857):[2]—

"In the hacienda of Concepcion, *which is situated on the banks of the Rio Florido*, there is a mass of native iron got from two small hills (*sic*) in the neighbourhood, which contain so large a quantity of magnetic iron ore that they appear to be wholly composed of that mineral. The mass referred to has a volume of about 60 cubic feet, and is composed of so malleable an iron that one of the *owners of the Rio Florido*, from curiosity, collected a considerable quantity of timber: setting fire to it they succeeded in making the mass red hot; and with much trouble, for the heat would not allow of anyone remaining near the mass, they severed a piece, and from it the owner had some horse-trappings (*montura*) made for him. The smith who forged them said that he had never worked any other iron with such facility."

The mass referred to by Conde is clearly that which is now at the hacienda of Concepcion, and is identical with the 'Rio Florido' mass mentioned

[1] *Amer. Jour. Sc.*, 1855, ser. 2, vol. 19, p. 160.

[2] *Bol. Soc. Mex. de Geog. y Estad.* Primera época, 1857, vol. 5, p. 251.

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by Simson; and the same may be said of the 'Rio Florido' mass of Weidner, Trask and Woodworth.

D. The two Chupaderos masses.

According to Castillo, only two masses are known to exist in the district east of Huejuquilla, namely those near the rancho (or hacienda) of Chupaderos, 17 miles east of the town: they are only 250 metres apart.

We have already proved that these masses are not, as has been supposed, identical with the ancient landmark referred to in the History of Philip the Second.

The earliest reference I have been able to trace relative to the Chupaderos masses is the following made by Bartlett,[1] who passed through the town of Huejuquilla in 1852, and sent a party to visit the masses of which he had heard mention:—

"Dr. Webb procured a guide in the town who professed to know where they were to be found: he set off from camp with our ten soldiers and three others of our party, but returned next day without having found them. It appeared that, on reaching the place designated, the guide became somewhat confused; and on being questioned more closely, acknowledged that he had not been there for twenty years: he declared it was not safe to go further on account of the Indians. The doctor, however, compelled him to lead them about for miles in every direction, but to no purpose."

Bartlett, nevertheless, expressed his belief in the existence of the masses:[2]—"From the various inquiries, made at Huejuquilla and at the hacienda of Concepcion, I learned of the existence of meteorites or masses of native iron in several places. Of those near the former place, of which Dr. Webb went in search, there is no doubt. Some of them are very large masses; while others are less than the one described (Concepcion)."

In a paper on the meteoric irons of the Bolson de Mapimi and its neighbourhood, after mentioning the masses at San Gregorio and Concepcion, Lawrence Smith[3] referred, in 1871, to "the locality of a huge meteorite lately discovered, of which no specimen has yet been detached, and which is said to be larger than any yet found in that locality:" and in 1876 he said:—"We have some account of one even larger than San Gregorio, located in the very centre of the desert."

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[1] *Lib. cit.*, vol. 2, p. 453.

[2] *Ibid.*, p. 458.

[3] *Amer. Jour. Sc.*, 1871, ser. 3, vol. 2, p. 337: 1876, vol. 12, p. 107.

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These remarks doubtless refer to the same mass, and were probably based on vague information relative to the meteoric iron of Chupaderos.

E. The Sierra Blanca masses.

Discovery of iron masses in the Sierra Blanca, near Huejuquilla.

The following paragraph appeared in the *Gazetas de México* for Wednesday, 8th September, 1784: "In the *Sierra blanca*, three leagues from the Villa Nueva de Huaxuquilla (*sic*) and twelve from El Valle de San Bartolomé, various masses of iron weighing 20, 30 and more quintals (hundredweight), have been discovered: fire has been put to them, and some pieces have been cut off with chisels: they proved to be workable, but owing to the expense the attempts have been given up."

Sierra Blanca is not given on any available map; but as the hills near Huejuquilla are composed of limestone the name Sierra Blanca would not be inappropriate to most hills in the neighbourhood.[1] Mr. Knotts of Parral sends me the information that the name was formerly used to indicate what is now termed locally the "Sierra de la Maloya," and that the sierra is eight leagues west of Huejuquilla: this must be identical with the Cerro Almoloya of the maps, which is eight leagues from Huejuquilla and five from El Valle measured in direct line; the distances do not accord very satisfactorily with those mentioned in the Gazette.

A fragment of meteoric iron, labelled "Ein Stück Meteoreisen aus der Sierra blanca unweit Villa nueva de Haxuquilla (*sic*) in Mexico," was mentioned by Kayser in 1834 in his description of the Mineral Collection of Dr. Bergemann:[2] the specimen eventually passed into the Berlin Collection, and from it have been cut the small pieces now in several Meteorite Collections under the name *Sierra Blanca*.

It is remarkable that in the above report there is mention only of the occurrence of masses in a locality of which the name is not to be found on the maps, and that there is not the slightest direct reference to the still larger masses now at Concepcion, San Gregorio, and Chupaderos in the same region, although two of the places are near a road which has for centuries been the important highway to Chihuahua and New Mexico, and one of the masses had been an important landmark at the end of the sixteenth century.

The report mentions the existence of "various masses, weighing 20, 30

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[1] *Memoir of a tour to Northern Mexico, &c.*, by Wislizenus, 1848.

[2] *Beschreibung der Min. Samm. des Herrn Bergemann*, Berlin, 1834, p. 465.

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and more quintals," of which only the fragment acquired by Dr. Bergemann would seem to have been preserved.

F. The Tule fragment.

The information relative to the iron of Tule is very slight. Castillo (1889)[1] says:—"In the Engineering School of Mexico is a small fragment of meteoric iron from Tule, Balleza, Chihuahua. There is no indication that the fragment has been severed from one of the large Chihuahua masses, or indeed from any other block."

The rancho of Tule, in Balleza, is 100 miles west of Chupaderos. In the absence of any history or description, the presence of the fragment at Tule within recent years is no proof that it had fallen in the neighbourhood, and still less that it had fallen with the Huejuquilla group, of which the terrestrial age was already beyond the memory of man more than three centuries ago.

Chemical analyses of the masses of the Huejuquilla group.

Though some analyses of fragments of masses of the Huejuquilla group have been made, the results are far from satisfactory: the difference in the numbers for a single mass (San Gregorio) are such that it is impossible to lay any stress on the variations in the analytical results for the members of the group.

	Humboldt's Durango.		San Gregorio.			Concepcion.		Chupaderos.
	a. Klaproth, 1807.	*b.* John, 1821.	*c.* Smith, 1871.	*d.* Rammelsberg, 1870.	*e.* Lumbier, 1880.	*f.* Rammelsberg, 1870.	*g.* Lumbier, 1880.	*h.* Rammelsberg, 1870.
Iron	96·75	91·5	95·01	89·6	90·4	..	89·0	..
Nickel ..	3·25	6·5	4·22	10·4	9·4	10·23	10·9	5·12
Cobalt ..		2·0	0·51					0·82
Phosphorus ..	..	..	0·08	..	..	..	..	..

a. The fragment was sent to Klaproth by Humboldt as from the large "Durango" mass. (*Beiträge zur chem. Kennt. d. Mineralkörper;* M. H. Klaproth, 1807, vol. 4, p. 102.)

b. Of the fragment analysed by him, Professor John of Berlin says that it was part of the "Mexican mass, well-known and already investigated by

[1] *Cat. Des, cit.*, p. 7.

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some chemists. It is that for which Humboldt is the authority, but I am uncertain as to whether the discovery was made by him or Sonneschmid." (*Schweigger's Journal für Chemie und Physik*, 1821, vol. 32, p. 268.) The specimen was doubtless part of the "Durango" mass, and one of those referred to by Humboldt as given by him to various European Collections.

c. The fragment was sent to Smith by Butcher. (*Amer. Jour. Sc.*, 1871, ser. 3, vol. 2, p. 336.)

d, *f*, *h*. The fragments of San Gregorio and Concepcion, and probably also that of Chupaderos (not "Chupanderes") were sent to Rammelsberg by Burkart. (*Neues Jahrb. für Mineralogie*, 1871, p. 852; *Die chem. Nat. d. Met.* von C. Rammelsberg, 1879, pp, 31, 32.)

e, *g*. The fragments were got from Urquidi, the owner of the Concepcion mass. (*Los Aerólitos de Chihuahua*, por Baltasar Muñoz Lumbier; México, 1880, pp. 16, 17.)

III. State of Sinaloa.

The Ranchito mass.

In 1876 Professor Barcena[1] mentioned the existence in Sinaloa of an enormous mass of meteoric iron more than 12 feet long, and stated that a chemical analysis by himself of some fragments sent to Mexico City was in progress: no detailed description, however, seems to have yet been published, but Barcena states that the components are essentially iron and nickel, and that the fragments are silver-white and grayish in colour.

Castillo (1889), in his list of Mexican meteorites,[2] gives the following information:—"The mass was found in 1871 at El Ranchito, 8 miles south-east of the mining centre Bacubirito, and measures 3·65m. long, 2·0m. broad, 1·50m. high: it is irregular in shape, and is traversed longitudinally by a fissure."

So extraordinary a mass, whether of meteoric origin or not, is worthy of careful study.

Bacubirito is in a direct line with Huejuquilla and El Valle, and is 127 miles south-west of the latter town.

IV. State of Durango.

As already shown, the large "Durango" mass, to the existence of which public attention was directed by Humboldt, is identical with one now

[1] *Proc. Ac. Nat. Sc. Philad.*, 1876, p. 122.

[2] *Cat. Des. cit.*, p. 5.

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situated in a corner of the hacienda of San Gregorio, near Parral, in the State of Chihuahua. Several comparatively small masses of meteoric iron, however, have been found in the present State of Durango.

1. The La Plata mass.

This was mentioned in the *Gazetas de México* for 1802,[1] a year before Humboldt's arrival in Mexico: the account is as follows:—

"In the Sierra Madre, at a distance of 13 or 14 leagues from Durango City, some farm-labourers have found a mass of metallic iron weighing upwards of 11 arrobas (275 lbs.): its shape was that of two moderate-sized troughs joined together at one end: it was about three inches thick in the middle: the grain appeared to be at all parts the same: the internal concavity was wholly covered with inequalities, such as are made by the feet of a big dog in moist earth. After it had been divided with much labour into two pieces at the place of junction, one of them was worked in the forge and a ploughshare made of it. It was found to plough as satisfactorily as one made of ordinary iron. From inquiry made of Don Pedro del Pozo, at the place of the discovery, we learn that it was found about 500 yards north-east of the hill called La Plata."

The second half of the mass, like the first, has disappeared.

La Plata is not indicated on any available map, but being in the Sierra Madre must be on the western side of the city.

2. The Guadalupe and Cacaria masses.

A. The Guadalupe masses.

a. A mass mentioned by Karawinsky.

A fragment of meteoric iron was acquired in 1884 from Freiherr von Karawinsky for the Vienna Collection: he had brought it with him from Mexico, and according to his statement to Partsch[2] it had been severed from a mass which weighed several hundred pounds and lay in the plain north-east of Durango. There is no statement that Karawinsky had himself seen the original mass: nor does he mention the distance from Durango City.

The Karawinsky mass was found on the Guadalupe Estate.

We have already seen that Weidner, when discussing the Mercado,

[1] Vol. 11, p. 1.

[2] *Die Meteoriten zu Wien*, 1843, p. 113.

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remarked in 1858 that the fragments given to Humboldt as Durango iron might very well have been brought from Durango and at the same time have been either got from the "Labor de Guadalupe, an estate near Durango City," or from one of the two big masses which were lying at "Concepcion and Rio Florido."

We infer that in 1858 it was regarded by Weidner as a recognised fact that metallic iron, not comparable in size with the Chihuahua masses, had been really found at the Labor de Guadalupe: a search for a definite statement of the discovery of metallic iron on that estate has been unsuccessful.

But I am informed by Dr. Carlos Santa Maria of Durango that the above extensive estate begins at five leagues north-east of the city; and this is the very direction which was assigned by Karawinsky for the locality of the mass of which he sent fragments to Vienna in 1884: hence it is extremely probable that the Karawinsky mass is the one which Weidner had in mind, when in 1858 he referred to the iron of the Labor de Guadalupe. No other record of the discovery of a Durango mass on the eastern side of the city before 1858 can be found.

b. A mass found at the rancho of La Pila.

A mass weighing 46·4 kilograms was turned up by a plough in 1882 at the rancho of La Pila,[1] nine leagues east of Durango. Dr. Carlos Santa Maria sends me the information that the rancho is part of the estate called La Labor de Guadalupe, which begins 5 leagues north-east of Durango and extends as far as La Pila, close to the hacienda of La Punta shown in Garcia Cubas' map as 10 leagues south-east of Durango.

On analysis by Dr. Janke (1884), the following results were obtained:—

Iron	91·78
Nickel	8·35
Cobalt	0·01
Phosphorus...	traces
Carbon	traces
	100·14

The specimen is now in the British Museum Collection.

Confirmation of the above suggestion as to the site of the Karawinsky mass is found in the statement of Brezina, that the etching figures of the mass are identical with those of the one ploughed up at La Pila.

[1] *Abhandl. Natur. Ver. zu Bremen*, 1884, vol. 8, p. 513.

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B. The Cacaria mass.

(*a*.) According to Castillo[1] (1889) this is a nearly round mass weighing 41·4 kilograms. It had been in use as an anvil by a blacksmith of Durango, according to whom it had been brought from the "plains of the hacienda of Cacaria." The hacienda of Cacaria is on the highway from Durango to Chihuahua, and is about 10 leagues, as the crow flies, north of the former city. The mass was presented by the late Gerando Ruiz to the Mexico Museum and is now preserved there.

Dr. Carlos Santa Maria tells me that the mass was in use at the forge for several years, and was sent to Mexico before 1870.

(*b*.) Tarayre[2] (1867) mentioned a block of iron, weighing about 200 kilograms, in use as an anvil by a smith in Durango City, and said to have been found in the neighbourhood. Tarayre does not state that he himself saw the mass: his statement, like that made by him at the same time relative to the (non-existent) mass "three-fourths buried in the plain," may be based on hearsay, and the estimate of the weight be very inaccurate.

No one claims to have seen two masses in use as anvils at Durango.

The distance, measured in a direct line, from the hacienda of Cacaria to the above-mentioned La Punta is 14 Mexican leagues (86 miles). But the actual dispersion of the Cacaria and Guadalupe masses may have been much less, for the plains are on the eastern or Guadalupe side of the hacienda of Cacaria, and the Guadalupe masses have been found on the Cacaria side of La Punta.

Though the Cacaria and Guadalupe masses have not yet been compared as regards their etching figures, there is every probability that they belong to a single and not very widespread fall.

3. The Mezquital mass.

A mass weighing about 7 kilograms was brought from Mexico, shortly before 1868; it was said to have come from San Francisco del Mezquital.[3] One of the districts into which the State of Durango is divided is called Mezquital: but the name San Francisco del Mezquital is not to be found on recent Mexican maps, and as San Juan del Mezquital and San Miguel de Mezquital are shown in Cubas' map as situated in the adjoining State of Zacatecas, it began to be doubtful as to whether San Francisco del

[1] *Cat. Des. cit.*, p. 5.

[2] *Archives de la Commission Scientifique du Mexique*, 1867, Paris, vol. 3, p. 270.

[3] *Comptes Rendus*, 1868, vol. 66, p. 573.

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Mezquital was in Durango at all. In an older map,[1] however, it appears as the name of the capital of the district of Mezquital, and is thus the town now called Mezquital: Dr. Carlos Santa Maria informs me that the elongated name San Francisco del Mezquital was used in the writings of the missionaries.

On analysis by Damour (1868) the following results were obtained:—

Iron	93·38
Nickel	5·89
Cobalt	0·89
Phosphorus...	0·23
	99·89

The main portion (7,513 grams) of the specimen was acquired for the British Museum Collection.

4. The Bella Roca mass.

A mass weighing 33 kilograms was found on La Bella Roca,[2] a peak of the Sierra de San Francisco, near to Santiago Papasquiaro: that town is 85 miles, in direct line, north-west of Durango City. The existence of the mass became known to Professor Ward in 1888, but he could obtain no information as to the date of the original discovery or the name of the discoverer.

On analysis by Whitfield (1889) the following results were obtained:—

Iron	91·48
Nickel	7·92
Cobalt	0·22
Phosphorus	0·21
Sulphur	0·21
Carbon	0·06
	100·10

The specimen has been cut into slices and distributed.

Masses from Durango belong to different types.

The Mezquital mass, on etching, is seen to differ completely from those of Pila and Bella Roca. Specimens of the three masses now in the

[1] *Bol. Soc. Mex. de Geog. y Estad.* Primera época, 1858, vol. 6, p. 374.

[2] *Amer. Jour. Sc.*, 1889, ser. 3, vol. 37, p. 439.

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British Museum were etched simultaneously: the octahedral structure of the Pila mass is so well defined that it could be traced on the polished face even before the etching; immediately after the application of the bromine-water, Widmanstätten figures manifested themselves on the faces of both Pila and Bella Roca, whereas no distinct figures could be seen on Mezquital even after prolonged action. After being washed and dried, however, the Mezquital face, though almost wholly dull, was seen to be still lustrous along straight parallel lines running completely across the face (130 mm. by 70 mm.) at intervals of one or two millimeters from each other: in fact, the etched face approximates in character to that of a Coahuila mass. This result is not inconsistent with the description of a face of small area by Daubrée, but is in complete disaccord with that of the etched face of a small fragment (149 grams) at Vienna.[1] Though meteoritic masses often vary in different parts, it seems more likely in this case that the Vienna specimen, which was acquired in 1872, had a wrong locality assigned to it, for with the exception of a fragment (170 grams) removed by Daubrée for the Paris Collection, the whole of the Mezquital mass is understood to have passed into the possession of the British Museum (7,513 grams) in 1870; and no fragment of this meteorite has ever been exchanged to Vienna.

Bella Roca is completely different in aspect from Pila, both in its enclosures and in the character of the Widmanstätten figures.

V. State of San Luis Potosi.

Meteoric iron has been brought from only two parts of the State of San Luis Potosi, namely Catorce and Charcas: as shown below, it is not at all impossible that the Charcas mass was transported to that town from the neighbourhood of Catorce.

1. The Catorce masses.

Three specimens are known to have been found quite near to Catorce and it may be assumed that they are products of a single meteor: they are:—(a) *the Descubridora mass, which is identical with the "Venagas" mass of Lawrence Smith*, (b) *a small mass seen by Burkart before* 1884, *but which has since disappeared*, (c) *a mass found in* 1885. Further (d) *Real del Guanqoche*, and (e) *Hacienda of Agua Blanca*, have been mentioned as localities for metallic iron.

[1] *Die Meteoriten-Sammlung in Wien* (Brezina), 1885, p. 60.

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(a) *The Descubridora mass.*

This mass, weighing 576 kilograms, now in the National Museum of Mexico, is stated to have been found between 1780-3.[1] Until 1778, when silver (the Descubridora vein) was accidentally discovered at the summit of the mountain-ridge close to the present town of Catorce, the district was quite uninhabited except by unsubdued Indians: within three years there was a population of 5,000, and by the year 1826 the population of the district amounted to 26,000.[2] To the east of the Sierra de Catorce the descent to the coast commences almost immediately, while to the west there is no ridge intervening between Catorce and Zacatecas. In 1778 the Sierra was covered with forests, but before 50 years had passed away not a tree or a blade of grass was to be seen. It thus seems likely that the large mass was found at the time when the careful examination of the mountain close to the present town of Catorce was made. After discovery, the mass was first moved to the hacienda of Poblazon, and was still there when Burkart was at Catorce in 1830, though he was unable to go to see it: it was next taken to the amalgamation works at San Miguel, near Catorce, to be used as a base for the ore-crushing stamps: it was then removed to the hacienda of Tanque de Dolores, and afterwards taken back to San Miguel; finally, it was purchased by Irizar, and presented by him in 1871 to the Society of Geography and Statistics of Mexico.

The mass of "Venagas" is identical with that of Descubridora.

In 1855 Lawrence Smith[3] wrote as follows:—

"Lieutenant Gouch (*sic*) also states that the intelligent but almost unknown Dr. Berlandier writes in his Journal of the Commission of Limits that at the hacienda of Venagas (*sic*) there was (1827) a piece of iron that would make a cylinder one yard in length with a diameter of 10 inches. It was said to have been brought from the mountains near the hacienda. It presented no crystalline structure and was quite ductile."

Smith refers in his later papers to the same statement without any variation of the details. Burkart[4] tried repeatedly and unsuccessfully to obtain information as to the locality of the hacienda; he remained under the impression that it was somewhere between the cities of Durango and

[1] *Bol. Soc. Mex. de Geog. y Estad.*, México. Segunda Época, 1872, vol. 4, p. 319. *La Naturaleza*, México, 1871-3, vol. 2, p. 290. *Cat. Des. cit.* (Castillo), p. 4.

[2] *Lib. cit.* (H. G. Ward), vol. 1, pp. 457, 471; vol. 2, pp. 232, 249, 259.

[3] *Amer. Jour. Sc.*, 1855, ser. 2, vol. 19, p. 160; 1869, ser. 2, vol. 47, p. 383.

[4] *Neues Jahrbuch für Min.*, 1858, p. 770; 1870, p. 691.

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Chihuahua. Brezina thought the mass might be one of the Coahuila group, and further suggests a theory which rests upon the assumption that the mass was actually cylindrical.[1]

In the first place "Gouch" is a mistake for "Couch," as already indicated. In the next place, Couch acquired for the Smithsonian Institution[2] all the voluminous manuscripts of Dr. Berlandier, who had died in 1851: hence it seemed possible that Couch might have obtained the above information from a hitherto unpublished record.

After a tedious search Berlandier's statement was at length traced: it was found on page 50 of the "*Diario de viage de la Comision de Limites —Lo Escribieron*—L. Berlandier y R. Chovel: 1850. 4to," and literally translated, runs as follows:—

"December 22, 1827. From the mining centre of Catorce to the hacienda of Vanegas (*sic*).

"On December the 22nd we set out from Catorce to rejoin the companions whom we were expecting to meet at Vanegas, six leagues distant in a north-east direction.

"Near the hacienda of Poblacion (*sic*) is a mass of iron from which could be made a cylinder a yard in height and ten inches in diameter. No part of its surface shows any sign of crystallisation: its edges are well rounded and the iron is very ductile. We had great difficulty in severing some fragments: before ourselves, two Englishmen, provided with good tools and manual assistance, had spent a whole day in cutting off some pieces which were really not very large. We were told that the mass had been brought a distance of some leagues, but we did not hear from what point nor the mode of occurrence. The people on the estate believe that the mass is insensibly moving in a direction from north to south. We vainly used our little logic in opposition to this belief."

It is obvious that this is the authority cited by Couch, and that there has been a confusion between the hacienda of Poblazon (Poblacion), where the mass was lying, and the hacienda of Vanegas (not Venagas) to which Berlandier's party was travelling on that day.

On analysis by Murphy (1872)[3] the following results were obtained:—

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[1] *Sitzungsber. Ak. Wien*, 1881, vol. 83, div. 1, p. 473.

[2] *Smithsonian Report* for 1854, pp. 15, 396.

[3] *La Naturaleza*, México, 1871-3, vol. 2, p. 290.

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Iron	89·51
Nickel	8·05
Cobalt	1·94
Sulphur	0·45
Chromium	trace
Phosphorus	trace
	99·95

(b.) *A small mass seen by Burkart before 1834.*

When at Catorce in 1880 Burkart heard of the mass then at Poblazon,[1] but could get no information about other masses: somewhat later, when at Zacatecas, he saw a roundish mass, apparently complete and not a fragment, in the possession of an Italian named Chialiva: it must have weighed 10 or 12 lbs. and was said to have been got at Catorce.[2] The mass has not been heard of since: Burkart lived at Zacatecas from 1828 to 1834.

(c.) *A mass found in 1885.*

A mass weighing 92 lbs. was found by a miner near Catorce in 1885,[3] and is now in the collection of Mr. Kunz. It must have been met with once before and thrown away, for on one side an opening 3½ inches long had been made, and a piece of a copper chisel had been left wedged in it: a long exposure was indicated by the partial oxidation of the copper. The copper was hardened by the ancient Mexicans by the addition of a small proportion of tin: recent analysis of one specimen proved the presence of 2·18 per cent. of the latter metal.[4]

On analysis of the iron by Mackintosh (1887) the following results were obtained:—

Iron	90·09
Nickel and Cobalt	9·07
Phosphorus	0·24
Schreibersite	0·60
	100·00

[1] *Neues Jahr. für Min.*, 1856, p. 286; 1857, p. 54.
[2] *Ibid.*, 1856, p. 286.
[3] *Amer. Jour. Sc.*, 1887, ser. 3, vol. 33, p. 233.
[4] *Anales del Museo Nacional de México*, 1877, vol. 1, p. 117.

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The above are the only masses from Catorce of which there is definite information; but the occurrence of iron at two other places in the immediate neighbourhood, namely, Real del Guangoche and Agua Blanca, was mentioned at the beginning of the century.

(d.) *Real del Guangoche, near Catorce.*

Del Rio[1] merely specifies "Real del Guangoche, close to Catorce" as a locality for native iron: he does not describe the specimens or the mode of occurrence: he mentions no other locality near Catorce, nor does he record even the existence of the mass at Charcas. No further mention of the Real del Guangoche has yet been traced, and we are thus ignorant of its precise locality: probably the statement really refers to the discovery of the Descubridora and Charcas masses; for it would be unlikely that news of the discovery of small specimens, now lost, should have been sent to Del Rio, and that information about the large masses, found many years before that date and still preserved, should have failed to reach him in Mexico City.

(e.) *Agua Blanca, near Catorce.*

Del Rio gives the following both in his Tablas Mineralogicas (p. 57) and in his Elementos de Orictognosia:[2]—

"Coeto and Cotero assert that iron occurs in bands (*cintas*), one or two inches thick, in conglomerate above the hacienda of Agua blanca (*sic*) near Catorce. I hope some other pupil will send a piece to the college, and thus confirm the existence of terrestrial metallic iron, as announced by Lehmann for the locality of Eibenstock in Saxony. The facts as yet established, however, seem rather to confirm the (meteoric) theory of Chladni."

Del Rio clearly considered the supposed mode of occurrence to require verification: nothing has since been heard of it and the exact position of Agua Blanca seems to be now unknown.

It may be remarked that it has since been established that the Eibenstock (or Steinbach) specimen, referred to above, is itself of meteoric origin.

2. The Charcas mass.

Sonneschmid, who according to his preface had spent 12 years in Mexico, states in his work, published in 1804:[3]—

[1] *Tablas Mineralogicas*, México, 1804, p. 57.
[2] Segunda Parte, 1805, p. 40.
[3] *Lib. cit.*, p. 288.

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"At the corner of the churchyard (*church*, according to Burkart) at Charcas, there stands a half-buried block of native iron: the part above the surface is about 2½ feet long and 1 foot thick. It is said that the mass was brought from the neighbourhood of San José del Sitio, an estate 12 leagues distant, and that in the same neighbourhood several other masses have been seen firmly embedded in a limestone-like rock."

No one has yet been able to determine the position of this estate: the name itself is an odd one; the extent of a Mexican estate was at that time generally expressed in Sitios, a Sitio being a square-league, and San José del Sitio thus differs from most of the Mexican names in being without any obvious meaning. In the time of Ward (1825-7) most of the haciendas of San Luis Potosi were vast sheep-walks.[1] If the estate lay in a direction north of Charcas, it would be near to Catorce, for the distance between the two towns is only 17 Mexican leagues.

Burkart[2] says (1857):—"I am informed relative to the occurrence of meteoric iron in the vicinity of Catorce and San Luis Potosi that it appears as if great quantities occur there on the limestone at the summit of the range, partly in big masses like those of Descubridora and Charcas, partly in masses of the size of the fist and smaller.

An approximate analysis by Meunier[3] (1869) gave the following results:—

Iron	93·01
Nickel and Cobalt	4·32
Residue	0·70
	98·03

The Charcas mass was taken possession of by the French in 1866, and is now preserved in the Paris Collection: according to the Paris List, the weight is 780 kilograms.

Possible identity of original locality of the Catorce and Charcas masses.

The Descubridora mass found in 1780-3, the one found in the same district in 1885, and that of Charcas, all show excellent Widmanstätten figures when etched: and though there are minor differences of character, they are only such as we might expect to meet with in small etched faces on different parts of even a single large mass. The figures, so far as it has yet been practicable to determine them, while insufficient to establish

[1] *Lib. cit.*, vol. 2, p. 228.

[2] *Neues Jahrb. für Min.*, 1857, p. 54.

[3] *Géologie Comparée; Étude sur les Météorites;* par S. Meunier, Paris, 1867, p. 40.

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either the simultaneity or the multiplicity of the falls to which the above masses belong, are not at all inconsistent with the view that the masses form a single group.

But when we remember that the removal and the original locality of the Charcas mass were still unforgotten at the time of the visit of Sonneschmid (1792-1804), and that the history of meteoritic masses passes into speedy oblivion whenever there is delay in publishing the record, we may fairly infer that the Charcas mass was found about the same time as that of Descubridora (1780-3); and probably in the vicinity of Catorce, since a careful search for silver-veins was made in the whole district after the discovery of the riches adjacent to Catorce itself: Sonneschmid says that the Charcas mass had been got from a place where several other masses had been seen, and Del Rio only specifies the neighbourhood of Catorce for San Luis Potosi iron: at the time of Ward's visit (1825-7) there was a good carriage-road from Charcas to Catorce,[1] and the transport of the large mass from the Catorce district to the church at Charcas would present no practical difficulty. Although Sonneschmid visited and described the mines of Catorce, the discovery of the Descubridora or other masses of iron in the immediate neighbourhood is unmentioned by him, unless the estate referred to as San José del Sitio was really in that region.

Taking everything into consideration, it is not improbable that all the masses yet found in the State of San Luis Potosi belong to a single fall, and have been met with in a district of no extraordinary area.

Specimen in the Poinsett Collection.

The specimen taken to the United States by Poinsett[2] and supposed by Smith to be possibly from Charcas, is probably a Toluca specimen, as shown below.

VI. State of Zacatecas.

Only one mass has been found in this State.

The Zacatecas mass.

The first known mention of the Zacatecas mass was made in the Gazetas de México for 3rd April, 1792, p. 59 :—

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[1] *Lib. cit.*, vol. 2, p. 232.

[2] *Amer. Jour. Sc.* 1868, ser. 2, vol. 45, p. 77.

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"From time immemorial there has been in the old St. Domingo Street of the city of Zacatecas a stone half-buried in the ground, which has been called Iron-stone by reason of its solidity. As to its origin there is only an oral tradition that it was found by one of the first colonists when working the Quebradilla mine, and has been lying near the door of his house ever since: it was noticed there by Sonneschmid, and recognised by him as native iron and recommended to the attention of the Government. Don Fermin Apecechea had it taken to his house and weighed: the weight was found to be 2,000 lbs. The mass is somewhat more than 1½ yards long, not so much in breadth, and somewhat over a quarter of a yard in thickness."

On page 155 of the same volume of the Gazette is published a letter of Sonneschmid, dated 24th July, 1792, which relates to the mass.

According to Burkart, the Quebradilla mine on the western outskirts of the city was worked immediately after the conquest of Mexico by the Spaniards.[1]

In 1804 Sonneschmid described the iron, but gave no history, simply stating that "no probable guess can be given relative to the origin of this remarkable specimen." Burkart lived at Zacatecas in the years 1828-34:[2] the mass was then in a private house, the residence of Don Angel de Abille in Tacuba Street. Burkart quotes at length the above statement from the Gazetas de México of 1792, but adds that at the time of his own residence at Zacatecas, there was one tradition that the mass had been brought "from the north," and another "that the mass was at Zacatecas when the Spaniards reached there."

Castillo (1889)[3] says that the specimen was "formerly in a street of the city of Zacatecas, and was afterwards removed to the hacienda of Cieneguillas, which belongs to the Gordoa family. It has the shape of a parallelepiped, and is 1·06 m. long, 0·50 m. broad, and 0·25 m. thick."

The mass mentioned by Cavaroz.

Writing from Durango on 21st September, 1864, Dr. Cavaroz says:[4]—

"We may note the existence of large fossils at a certain place called Los Zapotes, four leagues from Cuquio. At a very fine hacienda, at which

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[1] *Reisen in Mexico* (J. Burkart), Stuttgart, 1836, vol. 2. p. 58.

[2] *Neues Jahrb. für Min.*, 1856, p. 289.

[3] *Cat. Des. cit.*, p. 4.

[4] *Comptes Rendus*, 1864, vol. 59, p. 1099.

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we made a general halt before reaching Zacatecas, there is a mass of iron which was found long ago in that city. A piece has been separated with great difficulty to be taken to England for study. The mass which remains may be 70 cm. long, 80 cm. broad, and 25 cm. thick, and has an irregular rectangular shape."

The specimen thus referred to is doubtless identical with the old Zacatecas mass; and the piece said to have been taken to England for study is probably the very one, weighing about twenty pounds, which had been analysed and described in London by Dr. Hugo Müller in 1859. The Gordoa family have long owned fine estates near Zacatecas: according to Ward (1826),[1] they then had purchased the fine estate of Mal Paso near Zacatecas for 700,000 dollars, and had besides a fortune of a million dollars, acquired from the La Luz mine at Catorce which began to yield returns in 1806; there is a hacienda bearing the name Cieneguilla between Cuquio and Zacatecas.

On analysis the following results have been obtained by Dr. C. Bergemann[2] and Dr. Hugo Müller[3] respectively:—

	Bergemann.		Müller, 1859.		
	1849. I.	1857. II.	I.	II.	III.
Iron	85·09	85·42	89·84	91·30	90·91
Nickel	8·00[4]	9·73	5·96	5·82	5·65
Cobalt	0·67	0·44	0·62	0·41	0·42
Phosphorus ..	..	..	..	0·25	0·23
Sulphur	0·84	..	0·13	..	0·07
Silica	..	..	..	..	0·50
Copper	0·03	..	trace	trace	trace
Magnesium	0·34	..	trace	trace	trace
Residue	3·65	1·05	3·08	2·19	2·72
	98·62	96·64	99·63	99·97	100·50

VII. States of Mexico and Morelos.

The Toluca group.

Masses of iron have been brought from various localities in the States of Mexico and Morelos: it seems likely that everyone of them was originally found in the immediate neighbourhood of Xiquipilco, a small town four leagues due east of Ixtlahuaca, in the State of Mexico.

[1] *Lib. cit.*, vol. 1, p. 471.
[2] *Pogg. Ann.*, 1849, vol. 78, p. 406; 1857, vol. 100, p. 256.
[3] *Quart. Journ. Chem. Soc.*, 1859, vol. 11, p. 236.
[4] *Pogg. Ann.*, 1849, vol. 78: p. 410, says 7·999; table on p. 412, says 9·895: the sum of the given percentages is not 99·348 as there stated, but 100·348.

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So much has been written relative to this iron that it will be convenient to collect together the few original statements which relate to the actual discovery of the masses (Plate II.).

(1784.) "Æ" says:[1]—In the town of Xiquipilco, belonging to the District of Ixtlahuaca, native metallic iron is met with so pure that, without any other preparation than heating, it may be worked into any shape; as I have verified in two journeys, undertaken with the object of discovering if there were veins of this mineral, which would be of infinite utility: but my observations only verified that masses of various shapes and sizes are found scattered through the fields, and that the Indians keep a look out for them, though the iron is at first covered with a crust of ochre. The Indians of the town and the owners of the haciendas use no other for the fabrication of the necessary agricultural implements."

(1804.) Del Rio[2] gives the following as Mexican localities for native iron:—"Zacatecas, Real del Guangoche near Catorce, Province of Durango, *near Cuernavaca in Xiquipilco*, and in the Misteca."

(1811.) Humboldt,[3] who had been in Mexico in 1803-4, says:—"It is to Sonneschmid that we are indebted for a knowledge of the meteoric iron which is found at several places in Mexico—for example, at Zacatecas, Charcas, Durango, and if I am not mistaken, in the vicinity of the small town of Toluca."

(1826.) Wilhelm Stein,[4] in a letter of 23rd April, 1825, published by Nöggerath, says:—"I send a piece of native iron from Xiquipilco. The occurrence of this iron deserves a closer investigation; so far practically nothing is known; and on my first journey to Xiquipilco I did not succeed in clearing the uncertainty away, for notwithstanding my careful searches I was not fortunate enough to find a piece *in situ*. It is well known that a considerable quantity has been found in the neighbourhood during ploughing, and that it has been used for the manufacture of all kinds of implements."

(1831.) Alzate Ramirez[5] reported as follows:—

"From time immemorial, no iron has found its way to the town of Xiquipilco and to the neighbouring haciendas for the necessary purposes. The Indians of Xiquipilco collect what they can, for it is not abundant: the owners of the haciendas of Indege and Santa Isabel barter for it with the

[1] *Gazetas de México*, Wednesday, 15th Dec., 1784, No. 25, p. 201.
[2] *Tablas Mineralogicas*, México, 1804, p. 57.
[3] *Essai cit.*, vol. 2, p. 582.
[4] *Schweigger's Journal für Chemie und Physik*, 1826, vol. 47, p. 74.
[5] *Gacetas de Literatura de México, por D. Jose Alzate Ramirez*, Puebla, 1831, vol. 2, p. 381.

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Indians who chance to find it, generally at the beginning of the rains, when it becomes visible among the soil. The Indians of Xiquipilco make spades and axes of the iron, and the owners of the said haciendas use it for ploughs. About the year 1776, I went to Xiquipilco to see with my own eyes the famed native iron. I found two smiths established in the town who worked the native iron : in my sight they forged it and worked it into the shape demanded of them.

(1855.) Dr. Krantz[1] stated at Bonn on 8th March, 1855 :—"I received from Mexico last autumn four masses of meteoric iron which had come from the following places, said by him to be in the Valley of Toluca :—a 43 lb. mass from Tejupilco, masses of 26 and 6 lbs. from Ocatitlan, and a 19 lbs. mass from Ixtlahuaca."

(1856.) Gustav A. Stein,[2] brother of the above mentioned Wilhelm Stein, reported as follows :—

"Having heard that the iron was found at various places in the Valley of Toluca, I went myself in July 1854 to get definite information at the small town of Ixtlahuaca : thence I was directed to the hacienda Mañi, a league north of the Indian village of Xiquipilco. In the barn of the hacienda there was a mass of iron weighing 220 lbs. : its owner told me that it had been found about 15 years before, half a league south of Xiquipilco, among the rounded pebbles of a small brook, which even in rainy weather contains little water : close by, though not in the brook itself, was found a 5½ lb. mass. A third of a league east of this locality a mass weighing some 800 lbs. had been found about twenty years before my visit. Another mass, weighing 19½ lbs., had been found a quarter of a league north-east of Mañi : one also was found three-eighths of a league east of Mañi. I was told that in times now remote large masses had been found as far away as the hacienda Mayorazgo. Some old landowners, in the neighbourhood of Ixtlahuaca, told me that knowledge of these masses of iron had been got long ago from a smith who had worked them into ploughshares and axes without using steel. The Indians of the neighbourhood for the sake of a small reward used to search for the pieces, which were then forged in his smithy. The masses, whether large or small, are now become scarce. But in the course of years a large quantity must have been worked up or taken away. They were carried as merchandise to various places, whence it happens doubt-

[1] *Sitzungsb. d. niederrhein. Gesell. f. Natur- und Heilkunde zu Bonn*, 1855, p. xlvii.

[2] *Sitzungsb. d. k. Ak. der Wissensch., Mathem.-Naturw. Classe*, 1856, Wien, vol. 20, p. 218.

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less that masses of meteoric iron, though in each case originally got at Xiquipilco, have been known also under the names—Ixtlahuaca, Tepetitlan, Mayorazgo, Gavia and Toluca. A meteoric iron has lately been described as from 'Tejupilco in the Valley of Toluca.' I have no doubt that Tejupilco is a mistake for Xiquipilco. The town of Tejupilco is not in the Valley of Toluca; the town is well known to me, for it is only 9 leagues west of Arcos where I lived; and I have never heard of any find of iron in its neighbourhood. The specimens described by Dr. Krantz are certainly from Xiquipilco."

(1856.) Burkart[1] reported:—"I was told, when I dwelt in the neighbourhood, about 30 years ago, that the locality was Toluca, but I could get no meteoric iron there: I did not learn till later, when I was living at Zacatecas (1828-34), that the iron was really found at Xiquipilco, but in spite of all my efforts, I was not able to get a specimen of it. * * * I think Tejupilco is a mistake for Xiquipilco. I cannot venture to decide whether the specimens said to have been got from Ixtlahuaca and Ocatitlan were actually found there or were only purchased there: I am inclined to think the latter must have been the case."

(1857.) Krantz[2] reported that a special search had been made in the Valley of Toluca in 1856 at his request: no fewer than 69 masses were found and sent to him, but the heaviest only weighed 1¾ kilos., and the total weight was only 49¼ kilos.

(1858.) Von Babo[3] analysed a fragment of a specimen which weighed 237 grammes: according to Schleiden of Trojes in Mexico "it came from the neighbourhood of Sizipilec, in the Valley of Toluca, where similar pieces are found distributed over a considerable area, and are frequently turned up by the Indians when ploughing."

(1889.) Castillo,[4] in giving a list of the specimens preserved in the Mexico Collection, states as follows:—

"1. Meteorites of a single fall found at *San Juan de Xiquipilco*, in the Valley of Toluca, State of Mexico.

(a) Meteoric iron of *Ocotlan;* small fragment.

(b) Meteoric iron of *Tenango;* small fragment.

(c) Meteoric iron of the *Cerro de Santiago*, near the hacienda of Gavia; small fragment.

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[1] *Neues Jahrbuch für Mineralogie*, 1856, p. 299.

[2] *Pogg. Ann.*, 1857, vol. 101, p. 152.

[3] *Ber. über die Verhandl. d. naturf. Gesellschaft zu Freiburg i. B.*, 1858, vol. 1, p. 256.

[4] *Cat. Des. cit.*, p. 3.

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(d) Meteoric iron of the *Sierra de Monte-Alto*, District of Xiquipilco; small fragment.

(e) Meteoric iron of the hacienda of *Mañi*, District of Ixtlahuaca; small fragment.

It is in the neighbourhood of Xiquipilco that the largest number of fragments of every dimension have been found: some reach a weight greater than 45 kilos. The inhabitants discover these fragments either in the fields when ploughing, or in the ravines hollowed by the passage of the water after heavy rains.

2. Meteorite of *Ameca-Ameca*, State of Mexico. It is a small nodule of meteoric iron found in the town of Ameca-Ameca. It is in the National Museum of Mexico.

3. Meteorite of *Los Amates*, State of Morelos. It is a nodule of iron which was found among several specimens of iron-minerals brought from the rancho of Los Amates, on the road from Mexico to Iguala and in the neighbourhood of the latter place.

4. Meteorite of *Cuernavaca*, State of Morelos. It is a fragment of meteoric iron found, so it is said, on the road from Mexico to Cuernavaca, in the mountains. It is in the National Museum of Mexico."

We may remark, with Chladni, that the shower of iron must have fallen before, probably long before, the arrival of the Spaniards, or there would have been some surviving tradition of the occurrence, for the Valley of Toluca has been inhabited from time immemorial: the meteor of 1521, already referred to, is not known to have yielded any tangible material. Hence the time during which the masses have been known as desirable objects for smithy-work is also probably very long: the forging of them into agricultural implements was already in full swing about 1776: they were then regarded as a terrestrial product. Stein distinctly states that they were articles of merchandise, and were taken for sale to various towns in the neighbourhood. And it is worthy of mention, that in the only cases in which names of places not immediately near to Xiquipilco are attached, the early history of the specimens cannot be traced. Further, those who have inquired into the occurrence in the neighbourhood itself could only hear of discoveries having been made within a few miles of Xiquipilco; in fact, for the first 50 years after the visit of Alzate Ramirez scarcely any other name is mentioned. Stein was in the neighbourhood of Toluca at the time when the specimens said to have been got from Ocatitlan, Tejupilco and Ixtlahuaca, were sent to Krantz in Germany, and asserts that the original locality was certainly Xiquipilco.

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Del Rio (1804), who was living in Mexico City, it is true, cites a Mexican locality "near to Cuernavaca in Xiquipilco," but such a statement, as it stands, is unintelligible. Cuernavaca is farther from Xiquipilco than from the capital where Del Rio was located: as the crow flies, Cuernavaca is 52 miles from Xiquipilco, while each of those places is only 85 miles distant from Mexico City. It is almost certain that Cuernavaca, which has long been a well-known place, is given by Del Rio in error for Ixtlahuaca; and that it was intended to aid in specifying the approximate locality of the small Indian hamlet of Xiquipilco: in 1805[1] Del Rio incidentally referred to the masses of Xiquipilco without mentioning either Cuernavaca or Ixtlahuaca.

On the other hand, it is possible that a comma has been omitted during printing, and that the sentence as written by Del Rio was "*junto á Catorce, en Xiquipilco*," thus indicating two distinct localities: Cuernavaca, however, was not again mentioned as a locality for metallic iron till 1889.

As regards the meteorites of Cuernavaca, Ameca-Ameca, and Los Amates, mentioned by Castillo in 1889, there is, in the first place, no evidence that they have been examined and found to be identical in character with those from Xiquipilco. In the second place, even if the identity of character is ever proved, there will remain the possibility that the fragments have been transported from the Valley of Toluca.

The valley from Cuautla to Cuernavaca is a very fruitful one, and at the time of Ward's visit (1825-6) was one succession of beautiful haciendas: probably many of the Xiquipilco fragments were carried over the mountains to be sold at the haciendas, either as curiosities or as material for the manufacture of agricultural implements.

The Ameca-Ameca meteorite "is said to have been found in that small town." Ameca-Ameca is a town where there are now iron-foundries, and where "ploughs, castings, smoothing irons, mill-wheels and other articles are manufactured:" the road from Mexico to the valley of Cuernavaca and Cuautla passes through it.

Similarly the rancho of Los Amates is on a line of traffic: according to Castillo it is near to Iguala and on the road from Mexico to that town. As the railway from Mexico to Acapulco was planned to pass through both Cuernavaca and Iguala, those towns must be on a natural route to the Pacific coast.

The Ocatitlan (of Krantz) is probably the town of Ocotitlan, five miles

[1] *Elementos de Orictognosia*; segunda parte, p. 40.

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south-east of the town of Toluca, and not as Burkart supposed Xocotitlan or Hocotitlan 15 miles north-west of Xiquipilco.

Ocotlan (of Castillo) is probably a mistake for Ocotitlan, for the Sierra de Ocotlan is not in the State of Mexico at all, but on the south-western border of the State of Morelos and about 80 miles south of Cuernavaca.

Tenango (of Krantz) is the capital of its district, and is only nine miles south of the town of Toluca.

Sizipilec (of Von Babo or Schleiden) is not given in the maps: from Sizipilec to Xiquipilco is at first sight too vast a transition to be due to error of transcription or printing, but when written in German cursive hand, the two words present such a close similarity that there can be no doubt at all of the name Sizipilec having come into existence in that way: the German *X* has become *S*, *qu* has become *z*, *co* has become *ec*. In fact most of the Toluca specimens got into the market through Schleiden, as is stated by Stein: and his remarks relative to the mode of occurrence at "Sizipilec" are identical with those made in the case of Xiquipilco.

A similar transformation from Xiquipilco to Tejupilco (of Krantz) in German, is easily possible; and indeed a printed label, sent by Krantz with a specimen to the British Museum, is altered in Krantz's handwriting from Tejupilco to Xiquipilco, showing that he himself accepted the view expressed by Burkart that there was a mistake in his original version of the name.

A Mexican specimen in the Poinsett Collection.

A specimen found in Poinsett's collection of Mexican minerals was analysed by Lawrence Smith, who suggested that it might belong to the meteorite of Charcas.[1] Poinsett published notes of a journey made through Mexico in 1822, and was for some time the United States Representative at Mexico City.[2] Burkart saw the Charcas mass soon after Poinsett's journey, and there were then no marks indicating the removal of a fragment. Poinsett makes no mention of meteoric iron in the notes of his journey. Everything points to the specimen being really one of the small masses from the Valley of Toluca: we may add that a specimen of the Toluca iron was sent to the Berlin Collection from the Embassy at Washington.[3]

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[1] *Amer. Jour. Sc.*, 1868, ser. 2, vol. 45, p. 77.

[2] *Notes on Mexico made in the Autumn of* 1822 (Poinsett), London, 1825.

[3] *Beschreibung und Eintheilung der Meteoriten zu Berlin* (G. Rose), 1864, p. 60.

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Chemical Analyses of the Toluca iron.

Numerous analyses of Toluca masses have been made; the iron found by various chemists varies from 85 to 92 per cent.: a table of the results has been published by Buchner.[1]

VIII. State of Oaxaca.

In this State a large mass has been found at *Yanhuitlan:* identical with this are masses said to have been found at *Chalco* and *Cholula:* fragments of the same mass are in the collections under the name of *Misteca.*

1. The Yanhuitlan mass.

El Mosaico Mexicano, 1840, vol. 8, p. 219, states:—

"The following is extracted from the information supplied by José Lopez Ortigoza, Governor of the Department of Oajaca. The town of Yanhuitlan is situated in the Misteca alta, at a distance of 4 leagues from Teposcolula. Near this town is a hill called in the Mistec language Deque-Yucunino: at its foot, according to the accounts of the oldest inhabitants, some Indian labourers, while tilling the ground, found an extraordinary mass, which from the rarity of its characters attracted their attention, and they carted it as far as the town: unable to learn its origin or value they tumbled it into a corner where it long remained. Its shape and hardness induced Vicente Hernandez, the blacksmith, to transport it to his smithy, and he used it as an anvil for some years. In 1825, A. F. Morney (*i.e.* Mornay), an Englishman, saw the mass, and not without much difficulty cut off a piece which he afterwards analysed and found to contain iron, nickel and silica. About the years 1826-30 it was removed from Yanhuitlan, and was to have been placed in the Museum of Oajaca: its great weight and the bad roads made the undertaking so difficult, that at a short distance from Yanhuitlan the plan was given up, and the mass was left there. In 1832 the present Bishop of Puebla saw it, and also had a little piece cut off."

The mass, which weighed 421 kilos., was removed to the City of Mexico in 1864, and minutely described by Castillo and Rio de la Loza.[2]

2. The Cholula mass.

Buchner,[3] in the continuation of his meteorite-list, says in 1865:—

[1] *Die Meteoriten in Sammlungen*, Leipzig, 1863, p. 141.

[2] *Bol. Soc. Mex. de Geog. y Estad.*, 1865, vol. 10, p. 661.

[3] *Pogg. Ann.*, 1865, vol. 124, p. 599.

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"Cholula, Mexico. A meteoric mass of about 500 kilos. is said to have been just brought to the City of Mexico. From its weight it appears to be an iron meteorite. Further news is to be expected."

It is obvious from the above history, that the mass referred to by Buchner is really that of Yanhuitlan, and that there has been a confusion of the names Cholula and Teposcolula: in fact, Buchner omitted the Cholula mass from his later list of 1869.[1]

3. The Chalco mass.

Burkart,[2] however, in 1870, gave a list of Mexican meteorites, and among them:—

"Chalco, a town in the Valley of Mexico. No further news has been received relative to the iron meteorite of 500 kilos. which, according to Buchner (Pogg. Ann., vol. 200, p. 599), is said to have been taken to Mexico."

Buchner's statement is really in vol. 124, p. 599, and relates to the mass called by him Cholula; vol. 200 had not at that time (1870) been published.

Hence Chalco is a mistake for Cholula, itself a wrong version of Teposcolula, and the Chalco mass is identical with that of Yanhuitlan.

4. The Misteca Alta fragments.

Del Rio[3] (1804) mentions "La Misteca" as a locality for metallic iron. According to Humboldt,[4] "the Province of Oaxaca includes two mountainous districts which have been known since the most remote times under the names Mixteca and Tzapoteca. The ancient Mixtecapan is now divided into Upper and Lower Mixteca (Mixteca alta and baja). The Indians of La Mixteca are an active, intelligent, industrious people." As already stated, the town of Yanhuitlan is in Mixteca alta, and the large mass had been found long before Mornay noticed it in 1825.

In 1834, Partsch[5] acquired for the Vienna Collection a small piece of meteoric iron, and later stated as follows (1843):—

"From an Indian town in the Misteca, State of Oaxaca, Mexico. Relative to the existence of this meteoric iron nothing has hitherto been published. Freiherr von Karawinsky of Munich, who has repeatedly

[1] *Pogg. Ann.*, 1869, vol. 136, p. 605.
[2] *Neues Jahrbuch für Min.*, 1870, p. 692.
[3] *Tablas Mineralogicas*, p. 57.
[4] *Essai politique* &c., vol. 1, p. 263.
[5] *Die Meteoriten zu Wien*, 1843, p. 134.

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travelled about Mexico, brought the piece back with him. It was cut from a mass which lies in the above mentioned place, as he informs me by letter."

It is clear that the mass referred to by Karawinsky must be identical with the one which at that date was still lying near the Indian town of Yanhuitlan.

Burkart,[1] having applied to Drusina for a specimen of the Misteca iron, received a fragment in 1855, but got no information as to the exact locality: Castillo (1889) says that he himself gave the specimen to Drusina to be sent to Burkart, and is of opinion that it may be the truncated point of the Yanhuitlan mass.

It is obvious that all the fragments known as Oaxaca or Misteca have been cut from the single mass found near the town of Yanhuitlan, and that the existence of the mass was already known in the Capital in 1804.

The following analyses have been published:—

	Misteca.		*Yanhuitlan.*	
	Bergemann.[2]	Rammelsberg.[3]	Rio de la Loza.	Rammelsberg.[3]
	1857.	1869.	1864.	1869.
	S.G. 7·58	S.G. ——	S.G. 7·82	S.G. ——
Iron	86·86	——	96·58	——
Nickel	9·92	4·39	1·83	6·21
Cobalt	0·74	0·18	0·36	0·27
Calcium... ...	——	——	0·61	
Phosphorus ...	0·07	——	——	
Sulphur	0·55	——	——	
Residue	0·97	0·20	0·01	trace.
	99·11		99·39	

The results furnish another striking example of the impossibility of employing, for discriminatory purposes, percentage compositions assigned by different chemists on the basis of analyses made in different ways on different fragments of meteoric iron, which is always a more or less complex mixture of various chemical compounds: in the present case, the difference is doubtless chiefly due to the difference in the processes employed; Rio de la Loza called attention to the fact that some of the reactions, observed but not specified by him, were of so unexpected a character as to suggest the presence of an unknown substance.

[1] *Neues Jahrbuch für Min.*, 1856, p. 305.

[2] *Pogg. Ann.*, 1857, vol. 100, p. 246.

[3] *Zeitsch. d. deutsch. geol. Gesell.*, 1869, vol. 21, p. 83.

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IX. State of Guerrero.

The Caparrosa mass.

Castillo[1] in 1858, on breaking a piece of copper pyrites which had been brought from the Rincon de Caparrosa, south-west of Chilpancingo, State of Guerrero, found a nodule of metallic iron, weighing 341 grams, embedded in it. He reports that it shows Widmänstatten figures when etched, and that the copper pyrites occurs in a talc-schist.

A specimen discovered under such extraordinary circumstances, if really of meteoric origin, is worthy of a more minute examination and description.

Summary as regards the dispersion of Mexican iron masses.

In each of the States of Zacatecas, Oaxaca and Guerrero, only a single mass of meteoric iron has been found, and there is absolutely nothing to suggest that they do not represent independent falls.

In Sinaloa, likewise, only a single mass has been met with, and its characters have not been determined: a suggestion of a relationship with another group would rest on the slight fact that the site of an extremely large mass is in a straight line with two other sites where large masses are now lying.

In San Luis Potosi two localities are recognised, but there is a strong probability that the Charcas mass, which has undoubtedly been transported to that town from a distance, was brought from the neighbourhood of Catorce: and, even if this was not the case, there is no evidence that the mineralogical characters are such as to render separate falls improbable.

In Durango four or five distinct localities are known, but the characters of the only masses which have been examined point unmistakably to the falls of distant masses having been independent of each other.

In Mexico there has undoubtedly been a large shower of limited dispersion in the Valley of Toluca: the three remaining masses from Mexico and Morelos have not been examined, and are very small and portable: even if they have not been transported, they may be found on examination to present characters which will differentiate them from the masses of the Toluca shower.

From Coahuila many masses have been got, but it is extremely probable

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[1] *Cat. Des. cit.*, p. 1; *Verh. d. naturh. Vereines d. preuss. Rheinl. u. Westph.*, Jahrg. 22, Sitz. Mai 4, 1865, p. 72.

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that all of them were brought from a single district of very small area: the two Nuevo Leon masses have never been examined and had obviously been transported, perhaps from Coahuila or San Luis Potosi.

In Chihuahua three or four areas are represented: but of the masses found in that State only those of the Huejuquilla group have been examined, and that in a very incomplete way: the recognition of the singleness of the fall of the Huejuquilla group depends almost entirely on the general similarity of appearance of the large masses. If the masses really belong to a single fall, as the available information makes most probable, the maximum dispersion is now 66 miles: but one of the terminal masses, that of San Gregorio, is known to have been transported by the Spaniards on one occasion for 1½ leagues, while according to a tradition current three centuries ago it had accompanied the Indians when they journeyed southward to take possession of that part of Mexico.

The Index to the names of the more important persons and places mentioned in the foregoing pages will facilitate reference to the facts here collected together.

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A Visit to the Calcite Quarry in Iceland.

By J. L. Hoskyns-Abrahall, Esq.

[Communicated by the Secretary.]

[Read March 18th, 1890.]

In the summer and autumn of last year I paid a visit to Iceland, and as I had been told by my friend, Mr. Madan, that the difficulty of obtaining large pieces of clear calcspar for optical purposes had been exciting some curiosity as to the state of the quarry itself, and as the peculiarity of the deposit made it an object of interest, I thought it worth while to force Eskifjördhr[1] into my route. The narrow fjords of Sudhrmúla Sysla, of which Reydhartjördhr, the largest, bisects the East coast of Iceland, are cut out of an immense plateau, formed of horizontal sheets of volcanic rock—chiefly trachyte—between three and four thousand feet high. This has been subsequently eroded into sharp bare ridges with immense cliffs or steep slopes falling from them, parted by torrent valleys and fjords; the greater part of the district not reaching the present snow-line. It is on one of these slopes, which slants down at an angle of forty degrees into Reydharfjördhr, that the unique quarry of Iceland spar is found. It consists of a cavity in the rock about twelve yards by five, and some ten feet high, originally filled almost entirely, but now only lined, with immense crystals, which are fitted so closely together as to form a compact mass, like a lump of sugar with grains averaging ten inches across.

The Syslumadhur,[2] Jón Asmundarson Johnsen, had given me leave to examine the cave, and take as many specimens as I liked; but the permission was not of very much use, there being about five feet of water nearly all over the bottom; and such specimens as I did get involved doing severe penance in walking barefoot over the sharp crystals. The floor is covered with a thin layer of very fine chocolate-brown mud, which sticks as tenaciously to one's feet as to the crystals. I had to

[1] (dh = th in with.)

[2] Magistrate, public notary, receiver of taxes, liquidator, auctioneer, &c.

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resort to tooth-powder to get the latter clean, though the great heaps of spar which lie on the path-side and in front of the mouth of the cave were all washed by the rain till they were as bright and transparent as ice. The water now running through the cave is incapable of forming calcspar. It appears, like the surrounding rocks, to contain an excess of silicic acid, and either etches the surface of the spar wherever it comes in contact with it, or covers it with stilbite, the characteristic zeolite of the doleritic and basaltic rocks in Iceland. The rock in which the cave is formed is a dolerite, and darker in colour than the surrounding phonolite, which is traversed by veins of black and green pitchstone. In the neighbourhood of the spar it is disintegrated, coloured slightly with green-earth, and full of microscopic crystals of stilbite and calcite.

The quarry was worked till 1872 by Herra Tulinius, a Danish merchant of Eskifjördhr—the trading station is an hour and a half's ride from Helgastadhir, the nearest farm to the quarry. (In Iceland all distances are measured in terms of the hour's ride, *tima*, and the day's journey, *leidh*.) The Icelandic government in that year bought a quarter share of the quarry, and stopped the work, so that Tulinius was glad to sell them the rest. Five years ago an attempt was made to re-open it. One man was employed, and after spending about a week in the cave, he succeeded in pumping out the water and extracting a fine block of clear spar, which was sold at a high price in London. Here, however, the work dropped, and in consequence Tulinius remains the proprietor of the whole of the calcspar that is available for physical work, and naturally sells it at a price that is calculated to make his very moderate stock last for a considerable time.[1] The reason of the inaction of the Icelandic government is not very clear, but as the working of the quarry is, perhaps from patriotic motives, delegated to Herr Gunnarsson, an *Icelandic* merchant, whose nearest warehouse is at Seydhisfjördhr, a good day's ride from Eskifjördhr, it is hardly to be expected that the buried treasure will soon see the light. Perhaps too the specimens of the best quality have been already removed. Certainly clear pieces do not constitute the great mass of the spar, and if M. Labonne, who visited the cave in May 1877 (the water being at that time frozen), could extract it 'en assez grande abondance' (*Comptes Rendus*, 105, 1144, 1887), he did not leave much exposed for me to take two years later. M. Labonne speaks in his note of ramifications into the environing rock which have never been worked, and suggests that this investigation might increase the

[1] It is sold by Thor E. Tulinius, Slotsholmsgade 16, Copenhagen K.

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importance of the quarry; such ramifications as I could see were on a very small scale. On the other hand, the thickness of the deposit has not yet been ascertained. But it is said that the best pieces occurred near the surface. For the most part the calcite is rendered semiopaque by innumerable cracks, generally following the gliding and cleavage planes ($-\frac{1}{2}R$ and R), and apparently produced by the pressure of the spar itself, but sometimes following the conchoidal fracture: remarkable examples of the latter kind are in the British Museum.

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Sanguinite, a new Mineral; and Krennerite.

By H. A. Miers, M.A.

[Read March 18th, 1890.]

(*a.*) *Sanguinite, a new Mineral.*

THIS mineral was found upon several specimens of argentite from Chañarcillo which were acquired for the British Museum in 1886.

The specimens consist of argentite in large drusy octahedra implanted on quartz or calcite, and associated with proustite and a little asbestos.

The proustite is mostly in the form of small brilliant prisms with scalenohedral terminations $\{20\bar{1}\}$, capped by the rhombohedron $\{110\}$, which are grouped upon the argentite. But dispersed on the argentite, together with these crystals of proustite, are a number of fine glittering scales, which present at first sight precisely the appearance of the pyrrhosiderite or göthite of Siegen, having the same bronzy red colour, and a lustre resembling that of earthy haematite when seen on the matrix, that is to say partly by reflected and partly by transmitted light. Under the microscope the scales are easily distinguished from göthite; they are without striations, remain dark when rotated between crossed nicols, and appear of a nearly blood-red colour by transmitted light; whereas scales of göthite are striated in one direction, and exhibit marked differences of absorption when rotated above the polariser.

Sanguinite was subsequently found on an older specimen in the British Museum Collection which had been supposed to be göthite or fireblende. On this specimen the scales are associated with calcite, argentite partly converted into silver, and a little copper pyrites, but no proustite. The intimate association of the scales with proustite, their colour, and their obvious derivation as an alteration-product from argentite suggest that they are probably a sulph-arsenite of silver, a conclusion which is fully supported by the necessarily incomplete chemical examination.

A quantitative analysis is precluded by the paucity of material; the scales are so excessively thin that although they are very conspicuous

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upon the specimens owing to their brightness and colour, the whole if removed would probably weigh no more than a few milligrams. Some qualitative experiments have however enabled Mr. Prior and myself to prove the presence of sulphur, arsenic and silver. The material was carefully picked out scale by scale under the microscope and examined between crossed nicols, so that it was known to be free from proustite and argentite.

It is with difficulty soluble in strong nitric acid, behaving in all respects like proustite; the solution of several scales gave a perceptible precipitate with hydrochloric acid, soluble in ammonia.

About 50 of the scales, weighing altogether less than ·0003 gram, fused with sodium carbonate and potassium nitrate, and tested in the usual way for sulphate, gave a very evident precipitate with barium chloride. About the same quantity tested for arsenic by the Fresenius-Babo method gave a very distinct arsenic mirror; in the residue minute particles of metallic silver were visible, and treated with nitric acid it yielded a milky liquid containing silver cyanide, which became clear on addition of ammonia.

The only known minerals to which the scales might apparently be referred are proustite, xanthoconite, and the mineral from Chañarcillo described by Streng (*Neues Jahrb.* 1878, p. 917; and 1879, p. 547). The physical characters, however, so far as they can be observed, are as follows:—

Colour, by reflected light, black; by transmitted light, almost identical with that of proustite, but darker (Radde 1 h to 2 k), and yellowish red in the thinnest scales. Streak (colour of the powder), dark purplish brown (Radde 30 b nearly).

Crystalline system hexagonal or rhombohedral; fracture conchoidal.

The scales have a brilliantly reflecting surface, but are rarely smooth plates, being almost always curved and slightly crumpled. They are usually broken at the edges with a curved fracture, but are sometimes to be found with sharply defined rectilinear edges, which meet at an angle of 60°; there can be no doubt that they are true uniaxial hexagonal plates, for they remain dark between crossed nicols when viewed in the direction of their normal, but when tilted in any way are seen to be doubly refracting with an extinction which is always parallel to the normal.

The sign of the double refraction could not be determined on account of the extreme thinness of the scales; their average thickness is not more than 0·001 mm., and when 4 or 5 plates are superposed they become too opaque for optical examination.

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Sanguinite is completely distinguished from xanthoconite, and Streng's mineral (which is probably either fireblende or rittingerite), by its colour, streak, and optical character; these characters are also sufficient to distinguish it from fireblende, which it somewhat resembles, and from rittingerite.

The distinction between sanguinite and proustite may seem less conclusive, since both are sulpharsenites of silver, hexagonal, uniaxial, and almost identical in colour by transmitted light.

On the other hand proustite never occurs in anything resembling hexagonal scales; in fact the basal plane does not exist as a smooth surface on the mineral; moreover, the proustite associated with sanguinite, which has apparently been formed contemporaneously with it by the alteration of the same crystals of argentite, is of the usual habit.

Finally, the streak of sanguinite is a dark purplish brown, somewhat like that of miargyrite, but darker, and quite different from the streak of proustite, which is, as I have shown, so characteristic as to distinguish that mineral with certainty even from arsenical pyrargyrite.

Another specimen from Chañarcillo consisted of 6-sided scales, having very much the appearance of sanguinite, grouped upon calcite with a little proustite. These, however, were found to be darker in colour than the sanguinite, and between crossed nicols show a bisectrix in the centre of the field, and indications of two optic axes; they also display a twin lamination which is never found in sanguinite.

Their striking resemblance to that mineral suggests that they may be the corresponding sulphantimonite, especially as their colour is almost exactly that of pyrargyrite.

Possibly they may be referred to fireblende or rittingerite.

(*b.*) *Krennerite.*

Only three crystals of this rare telluride of gold from Nagyag have previously been measured; one by Krenner (*Ann. f. Phys. und Chem.*, vol. i. 1877, p. 636), who described the mineral under the name of Bunsenin; another by vom Rath (*Zeits. f. Kryst.* i. 1877, p. 614), who substituted the name Krennerite; the third by Schrauf (*Zeits. f. Krys.* ii. 1878, p. 235). Their observations lead to axial ratios, which do not differ much either from each other or from those adopted by myself.

The following description of a crystal taken from a specimen in the British Museum Collection supplies confirmatory measurements, and contributes 6 new forms to the 16 previously recorded.

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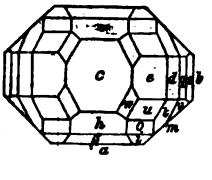

In this specimen the Krennerite occurs in small striated prisms upon crystallised quartz, together with a little iron pyrites and some small crystals of tetrahedrite which are coated with copper pyrites; most of the prisms are terminated by the bright and characteristic basal cleavage plane; the one which was measured presented 10 forms which have previously been observed, namely:—

a	010	$\infty\breve{P}\infty$	*o*	111	P
c	001	0P	*i*	232	$\frac{3}{2}\breve{P}\frac{3}{2}$
m	110	∞P	*h*	011	$\breve{P}\infty$
e	101	$\breve{P}\infty$	*ρ*	021	$2\breve{P}\infty$
u	212	$\breve{P}2$	*b*	100	$\infty\breve{P}\infty$

and six new forms, namely:—

d	201	$2\breve{P}\infty$	*t*	211	$2\breve{P}2$
q	801	$8\breve{P}\infty$	*v*	682	$8\breve{P}2$
s	401	$4\breve{P}\infty$	*w*	214	$\frac{1}{2}\breve{P}2$

This prism was 0·5 mm. long and 0·75 mm. broad.
The axial ratios obtained from the measurements are

a : b : c =	...	1·0651 : 1 : 0·5388
Krenner found	...	1·0661 : 1 : 0·5440
vom Rath found	...	1·0630 : 1 : 0·5362
Schrauf found	...	1·0643 : 1 : 0·5399

Of the remaining six forms previously observed, which are not found on this crystal, it may be remarked that four belong to the prism zone in which the faces are vertically striated and scarcely capable of exact measurement; the terminal faces are bright and smooth. The following table contains all the reliable measurements of Krenner and vom Rath:—

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	Miers.		Krenner.		vom Rath.	
	Observed.	Calculated.	Observed.	Calculated.	Observed.	Calculated.
	° ′	° ′	° ′	° ′	° ′	° ′
c e	26 50	..	27 0	27 2	..	..
c h	28 19	..	..	..	..	28 12
c d	45 20	45 20	..	..	..	..
c q	56 35	56 37	..	..	..	..
c s	63 48	63 42	..	..	..	..
c o	46 52	47 8½	..	..	..	..
a i	54 11	54 12	..	..	54 30	54 19
a o	64 21	64 19	..	..	64 15–30	64 24
a u	76 27	76 29	..	76 23	76 30	76 32
e u	29 47	29 49	30 5	30 2	..	..
a m	43 5	43 12	43 10	..	43 15	..
c t	49 4	48 54	..	..	..	..
c v	59 52	59 49	..	..	..	..
c w	15 58	15 59	..	..	..	..
c m	..	72 0	71 58	..	72 1½	..
e u	13 33	13 31	13 41	13 37	..	..
m u	..	61 55	61 46	61 42½	..	..
u u	..	52 14	52 20	..	..	..
i h	23 56	23 51	..	..	..	..
h u	29 2	29 0	..	..	..	..
u d	22 44	22 46	..	..	..	..
c o	36 26½	36 28	..	..	..	..

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Notes on Bowenite or Pseudo-Jade from Afghanistan.

By Major-General C. A. McMahon, F.G.S.

[Read May 20th, 1890.]

A STONE called *sang-i-yashm*[1] in Persian, which has some points of resemblance to jade and is sometimes mistaken for it, is utilised at Bhera, in the Shahpur District of the Panjab, for the manufacture of dagger hilts, knife handles, caskets, amulets, and other articles. It is also found useful in mosaic work.

I am indebted to Mr. J. Wilson, B.C.S., Deputy Commissioner of the Shahpur District, for several specimens of the stone in the unworked state, and for information regarding its place of origin. Other specimens I obtained from my son Lieut. A. H. McMahon, Assistant Commissioner, Kohat.

The *sang-i-yashm* is a hard species of serpentine which seems to correspond very closely to that named bowenite, after Dr. Bowen, who, in 1822, published an analysis[2] of a mineral from Smithfield, R.I., which up to that date had been called nephrite.

In 1853 the Smithfield bowenite was re-examined by Messrs. J. Lawrence Smith, M.D. and George J. Brush,[3] who proved its identity with serpentine.

The hardness of the Smithfield mineral was said by Dr. Bowen to be equal to that of felspar. J. D. Dana put it at 5·5 to 6, E. S. Dana at 5·5, and Smith and Brush at 5. The Afghan mineral has a hardness of 5.

The Sp. G. of the Smithfield bowenite, according to Dr. Bowen, varies from 2·59 to 2·787. I found 2·59 to be the Sp. G. of the Afghan mineral.

The following analysis (No. I.) of the Afghan *sang-i-yashm* was made in the British Museum Laboratory by Mr. G. T. Prior, M.A., and has been kindly communicated to me by Mr. Fletcher, F.R.S., the Keeper of the Mineralogical Department. I also give for facility of reference Dr. Bowen's analysis (No. II.) and Smith and Brush's analyses (Nos. III. IV. and V.).

[1] *Sang* means stone. *Yashm*, according to Forbes's and Platt's dictionaries, is a jasper "especially from China, supposed to be an infallible charm against lightning."
[2] *Amer. Jour. of Science.* 1st Series, V. 346 (1822).
[3] *Ibid.* 2nd Series, XV. 212.

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	I.	II.	III.	IV.	V.
Silica	44·73	44·69	42·20	42·56	42·10
Magnesia	42·64	34·63	42·50	43·15	41·23
Alumina	0·32	0·56	trace	trace	trace
Ferrous Oxide .	0·33	1·75	1·56	0·95	1·11
Lime	trace	4·25	trace	..	1·90
Manganese	..	trace	..	..	..
Water	12·21	13·42	13·28	12·84	12·77
	100·23	99·30	99·54	99·50	99·11

The theoretical formula for serpentine is: magnesia, 43·48; silica, 43·48; water, 13·04. The analysis of the Afghan mineral comes very near this standard, and corresponds closely with the analyses of American bowenite made by Smith and Brush.

As regards the lime found in bowenite by Dr. Bowen, Smith and Brush remark:—"The large amount of lime obtained was doubtless due to the limestone and tremolite with which it is often very intimately associated; much care is required to separate those substances entirely from the bowenite, but the mineral so purified, contains no lime."

The colour of the Smithfield mineral is said by Bowen to be "bright apple-green, sometimes tinged with blue;" and by J. D. Dana to be "apple-green or greenish white."[1] My specimens of the Afghan rock vary in colour from a dark greenish grey to a very pale sea-green mottled with white. Some specimens are said to be delicate apple-green.

The Smithfield mineral Dr. Bowen tells us is found "in large nodules" imbedded in "white primitive limestone." The Afghan bowenite appears to occur in rock masses at the head of one of the mountain gorges that run down from the Safed Koh into the valley of the Kàbul river. A man of Bhera, from whom Mr. Wilson derived his information, "went in search of the stone about forty years ago. He says he proceeded to Gandàmak[2] on his way to Kàbul, and from thence travelled up a gorge to the south for about thirty miles. At the head of the gorge he came to a rock where there are great quantities of the stone." "It is sold on the spot at about Rs. 2/8 to 3 Rs. a maund (5 shillings the cwt.). Some of the bits at Bhera have two marks of blasting bores on them. They weigh up to a cwt." After import to Bhera in the Shahpur District of the Panjab it is sold by weight "at about Rs. 40 per maund, or 74 shillings per cwt., and the inferior quality at 10 Rs. per maund, or 18 shillings per cwt. There are only three shops in Bhera of the workers of the stone, and they have between them used up about 5 maunds in three years."

[1] *System of My.* 1882, p. 465.

[2] Gandàmak is between Jalàlàbàd and Kàbul.

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The *sang-i-yashm* is partially decomposed by hydrochloric acid, and is completely decomposed by hot concentrated sulphuric acid on prolonged digestion.

When a thin slice of the Afghan bowenite is examined under the microscope between crossed nicols it breaks up into a mass of minute doubly refracting fibrous crystals standing out against a dark background; the latter being due in part to the over-lapping of felted fibres, and consequent compensation, and in part to the extinction of such of the crystals as lie in the same azimuth as one or other of the crossed nicols.

Whenever the cleavage of the original mineral from which the bowenite has been derived can be made out, one set of doubly refracting fibrous crystals are found to lie parallel to it. A second set may be observed at right angles to the first; whilst a third more sparsely distributed series of crystals may also be seen, which indicate that the parent mineral possessed a third, and less easy cleavage, diagonal to the other two.

In other parts of the thin slices examined the crystals assume a somewhat feathery appearance, or arrange themselves in sheaf-like sprays. In some slices the doubly refracting crystals are somewhat micaceous, and the central portions of them exhibit a marked but discontinuous cleavage. These micaceous crystals cannot be talc, inasmuch as they never exhibit colours higher than the blue, yellow, and red of the first order of Newton's scale and no parts of the slices have a hardness of less than 5.

J. D. Dana in his System of Mineralogy remarks :—"If marmolite or thermophyllite is truly crystallized serpentine, as seems probable, the crystallization of the species is actually micaceous like that of chlorite and talc."

On the whole I see no reason to doubt that all the doubly refracting portions of the thin slices of bowenite examined are true serpentine. When thin slices of the rock are digested in sulphuric acid, the fibrous structure of the mineral is well brought out.

The optical properties of the doubly refracting crystals of bowenite coincide with those of serpentine. Extinction is uniformly straight; the major axis is normal to the axis of the fibres; and the crystals that exhibit cleavage, or fibrous structure, do not yield a bisectrix in converging polarised light. The refractive index of the Afghan mineral is evidently close to that of Canada balsam.

The *sang-i-yashm* appears to be a very pure serpentine. In some slices a few microscopic dots of magnetite may be made out, and some microscopic crystals of pyrites. There are also scattered through the slices

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granules of a mineral which either remains absolutely dark when revolved between crossed nicols or only shows the feeblest possible glimmer, which may be due to the under-lapping of some of the serpentine. It does not exhibit crystallographic outlines or definite cleavage. It has a rough and cracked surface; it frays out at the ends into needles, and does not exhibit any metallic lustre. It has a high refractive index, and appears to be insoluble in sulphuric acid. In some respects it looks like garnet, but it does not possess the habit of that mineral. Sometimes it occurs in strings in a way to suggest that it is a secondary product; at other times it is penetrated by channels of serpentine very much in the way in which remnants of olivine are found in serpentine. On the whole I am disposed to think that it represents one of the original constituents of the parent rock, and possibly may be a pseudomorph after olivine. I hesitate to give the mineral a definite name.

This mineral, whatever it is, leads to the consideration of the character of the parent rock. The fact stated above relative to the structure of portions of the bowenite indicates that one of the minerals of the original rock possessed a triple cleavage, the two principal planes of which were at right angles to each other: a circumstance which enables us to identify it as pyroxene.

There is no evidence, beyond the suggestion as to olivine alluded to above, to show what the other constituents of the parent rock were, but there is nothing in the microscopic evidence to negative the supposition that the principal one was olivine. The almost complete leaching out of the iron destroyed all trace of *Maschen-structur;* but we must suppose that the original rock was, to a considerable extent, made up of a magnesian mineral, as otherwise the magnesia of the pyroxene of which the rock was evidently in part composed, could hardly have been levelled up to the amount required for its conversion into serpentine.

On the whole the probabilities of the case are in favour of the parent of the Afghan bowenite having been, as in the ordinary run of serpentines, some variety of peridotite.

The conversion of the original rock into pure serpentine has been so complete, that little microscopic evidence remains of the mode in which the aqueous agencies that effected the change in the rock worked their way through its molecular structure. Still there is enough to show that these agents availed themselves of all the facilities that existed; a few straight cracks with microscopic deposits of iron along their margins may, on careful search, still be traced; and, as before stated, when cleavage planes existed the serpentine crystals were formed in alignment with those planes.

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The curved, feathery, and sheaf-like crystals were probably formed in the olivines of the parent peridote; curved cracks are commonly observed in this mineral, but regular cleavage is rarely, if ever, seen in sections made for the microscope. Other indications of aqueous agents may be noticed in the occasional deposit of a substance, reddish brown in reflected and transparent in transmitted light, that *runs with* some of the feathery sprays of crystalline serpentine. This reddish brown substance is evidently a secondary product, and it helps to throw light on the mode in which the curved and feathery crystals of serpentine were themselves formed.

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On the Relations between the Gliding Planes and the Solution Planes of Augite.

By Professor John W. Judd, F.R.S., F.G.S.

[Read May 20th, 1880.]

NONE of the mineralogical problems of the present day are of greater importance than those which deal with the nature and causes of the modifications which crystallised bodies undergo as a consequence of changes in their environment. It is above all things necessary that we should clearly discriminate in every case between the characters of minerals which are *original* and *essential*, and those which are *accidental* and *secondary*, and which result from the action of various mechanical and chemical forces upon crystals, subsequently to their formation. No fact is more certain than that crystallized minerals, without losing their identity, may have their chemical composition altered within certain (often very wide) limits; and that, as the result of chemical action or mechanical strains, profound changes may take place in all their optical and other physical properties.

It has long been known that certain augites—especially varieties pale in colour and poor in alumina and iron—often exhibit a lamellar twinning parallel to the basal plane {001}. These varieties, which are especially abundant in crystalline limestones, are also found in certain igneous rocks; and Rosenbusch proposes to group them under the name of malacolite. In 1886, Mügge showed that when untwinned crystals of this variety of augite (which he calls diopside) are subjected to deforming stresses by Daubrée's method of enclosing the crystal in lead and subjecting it to pressure, lamellar twinning on the basal plane was produced artificially. The varieties operated upon by Mügge were the well-known malacolites (diopsides) of Ala and Achmatowsk.[1] As long ago as 1827 a distinguished pioneer in crystallographic research, William Phillips, showed that the Whin-Sill of Teesdale contains an augite, which besides

[1] *Neues Jahrb. für Min. &c.* 1886, I. p. 185. *Ibid.* 1889, I. p. 238.

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presenting a somewhat unusual development of certain faces, also exhibits a lamellar structure parallel to the basal plane.[1]

In 1875 Dr. Hawes described an augite occurring in a diabase from the Connecticut Valley, which exhibits the same structure.[2] An analysis was given of this variety by Dr. Hawes, and a section reproduced by photography is contained in Rosenbusch's well-known work.[3]

In 1884, Dr. Osann showed that an augite with lamination parallel to the basal plane occurs at Költer and other localities in the Faroe Islands, and that this is really a variety, like that of the Connecticut Valley, rich in iron and magnesia. In the same year Mr. Teall re-examined the augites of the Whin Sill, and showed that Phillips's determinations were correct; he also proved that in chemical composition these Whin-Sill augites agree very closely with those of the Faroe Islands described by Osann,[4] and those of the Connecticut Valley described by Hawes.

In my study of the rocks of the Western Isles of Scotland, I have found that augites exhibiting a lamellar structure parallel to the basal plane are extremely common, especially in Ardnamurchan, both among the older tertiary lavas (those erupted before the basalts of the plateaux) and in those of newer tertiary age (lavas that made their appearance at the surface subsequently to the basalts). These augites agree very closely with the forms described from the Faroe Islands by Dr. Osann. They differ from those described by W. Phillips and Mr. Teall in rarely, if ever, exhibiting the simple twinning parallel to the orthopinacoid {100}, and thus the "herring-bone" structure of Mr. Teall is very seldom seen in them.

My study of the Scottish gabbros long ago led me to the conclusion that the lamination parallel to the orthopinacoid, which is found in diallage, was the result of chemical action, taking place at great depths, along certain definite planes (solution-planes) in the crystals of ordinary augite.[5]

I showed that the planes first acted on are those parallel to the orthopinacoid {100}; that next the planes parallel to the clinopinacoid are affected {010}; and that finally a similar action is set up along the planes parallel to the base {001}. In this way the structures are eventually produced which characterise the so-called "pseudo-hypersthene."

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[1] *Camb. Phil. Trans.* Vol. II. p. 166. *See also* Phillips's Mineralogy, 3rd ed. (1823), p. 59.

[2] *Am. Journ. Sc.* 3rd ser., Vol. IX. (1875) p. 187.

[3] *Mikroskopische Physiographie der petrographische wichtigen Mineralien*, 2nd edition (1885), table xix. fig. 6.

[4] *Quart. Jour. Geol. Soc.* Vol. XL. (1884) pp. 647-8.

[5] *Quart. Jour. Geol. Soc.* Vol. XLI. (1885) p. 367.

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Every petrographer is familiar with the fact that the common twinning of augite upon the orthopinacoid {100} shows a tendency towards repetition, so that we find one or more twin-lamellæ running through the middle of the crystal. Recently Professor Renard, in his studies of the rocks of Teneriffe, has been able to show that numerous twin-lamellæ are sometimes formed parallel to the orthopinacoid, there being a curious tendency towards the crowding of the twin-lamellæ towards the middle of the crystal.[1]

These facts, showing the intimate relation which exists between the simple twinning of a crystal and the lamellar twinning which may be brought into existence by mechanical means, are of very great interest.

Now it is a very interesting circumstance that in some of the most highly crystalline varieties of andesite from Mingary Castle, in Ardnamurchan, we find in the porphyritic augites the planes of alteration parallel to the basal plane well developed, and the commencement of a second plane of lamination parallel to the orthopinacoid.

Let us proceed to consider the explanation of these facts. Even if the view put forward by Van Werveke,[2] and to some extent supported by Rosenbusch, be the true one, that the lamellar structure in diallage is itself determined, in the first instance, by pressure, then we must conceive of augite as being capable of lamellar twinning either parallel to the basal plane or to the orthopinacoid. If the former are produced, chemical action results in the formation of a laminated augite like that of Teesdale, Connecticut, Faroe, and Ardnamurchan. But if the latter are produced, then the result is an ordinary diallage. If this explanation be the true one, then there is a very remarkable analogy between the lamellar twinning of the augites and that of the plagioclases.

That augites exist with two systems of lamellar twinning, one parallel to the orthopinacoid and the other to the basal plane, and hence cutting one another at a high angle, I have been able to satisfy myself upon many occasions. Beautiful examples of the kind occur among the pale coloured augites in the "hemithrène" (red marble) of the island of Tiree. Some of the sections of these doubly twinned augites exhibit the most startling resemblance to sections of plagioclase felspars, with both albite and pericline twinning; so that but for their higher refraction and double refraction, mistakes might easily arise in their identification.

In 1886, I showed by experiments with calcite that when lamellar-

[1] Report on Rock Specimens collected on Oceanic Islands. *Challenger Report. Physics and Chemistry*, Vol. II. (1889) p. 1.

[2] *Neues Jahrb. für Min. &c.* 1883, II. p. 97.

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twinning has been developed in a crystal, the gliding planes become the "solution-planes," which are first attacked, in preference to the normal solution-planes of the crystal.[1]

These considerations enable us, I believe, to give a complete explanation of the curious anomalies presented by augite-crystals. If, as I incline to believe, the orthopinacoid {100} is the principal normal solution-plane of augite, then chemical action operating at great depths along planes parallel to the orthopinacoid, leads to the development of secondary inclusions along them and results in the formation of ordinary brown diallage. If, as chemical action becomes more intense with increased pressure, a second solution-plane is attacked, this is the clinopinacoid {010} ; and next the third plane of chemical weakness, the basal plane {001}, is subjected to the same action. Thus in the end we get pseudo-hypersthene.

But if, previously to the commencement of chemical action, lamellar twinning parallel to the basal plane has been set up by pressure, then this becomes the first solution-plane, and is attacked before the normal solution-plane—the orthopinacoid.

As the result of the development of gliding planes parallel to the base, and the chemical action which takes place along them, the augite-crystals in the much altered rocks of Mingary Castle are often found broken up into fragments, which are more or less displaced, and thus a curious faulted appearance is given to the crystals.

In many cases, too, the development of the enclosures along the planes attacked has been followed by still further and very profound alteration ; chloritic and serpentinous products being formed in abundance along these planes. These much altered augites have just the same relation to the less altered ones that the green diallages have to the ordinary brown diallage.[2]

It is often asserted that the diallagic modification of augite is determined by a peculiar chemical composition ; and a similar suggestion has been made in the case of those augites which present a laminated structure parallel not to the orthopinacoid, but to the basal plane. But for these conclusions I must confess that I am totally unable to find any warrant. The pale green diopside of Rum, containing only 5 per cent. of iron-oxides, assumes the diallagic condition equally with the dark black

[1] *Mineralogical Magazine*, Vol. VII. (1886) p. 81.

[2] The altered augites of Mingary Castle are figured in Plate XIV. figs. 1 and 2 of Vol. XLVI. *Quart. Jour. Geol. Soc.* (1890). Professor G. H. Williams has recently called attention to the importance of a similar parting parallel to the basal plane which is found in the hornblende of St. Lawrence County, New York. *Am. Jour. Sc.* ser. iii. Vol. XXXIX. (1890) p. 352.

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augites of Loch Scavaig, in Skye, with 15 per cent. of iron-oxides. Indeed, every variety of augite, so far as my experience goes, may be found, when subjected to the proper conditions, to assume the diallagic modification. In the same way, the twinning and chemical alteration parallel to the basal plane is found equally developed in the pale coloured, slightly ferriferous malacolites and in the black, highly ferriferous augites of Teesdale, Költer, and Ardnamurchan. This is illustrated by the following table :—

COMPOSITION OF AUGITES EXHIBITING LAMELLAR TWINNING PARALLEL TO THE BASAL PLANE (001).

	Achmatowsk. *Hermann.*	Ala. *Waskenroder.*	Whin Sill. *Teall.*	Költer. *Osann.*	Connecticut Valley. *Hawes.*
Silica	53·97	54·15	48·41	50·21	50·71
Alumina	—	0·20	4·05	3·24	3·55
Ferric Oxide	—	—	2·36	—	—
Ferrous Oxide ..	2·00	2·51	15·08	17·40	15·30
Manganous Oxide ..	—	0·18	0·37	—	0·81
Lime	25·60	24·74	15·98	13·92	13·65
Magnesia	17·86	18·22	12·14	14·05	13·63

These analyses prove conclusively that a tendency to the development of lamellar twinning parallel to the basal plane is not confined to any one variety of augite. It is equally certain that the separation along the planes parallel to the ortho pinacoid which is characteristic of diallage is found alike in aluminous and non-aluminous augites, and in varieties with different proportions of lime, magnesia, and ferrous oxide.

For the sake of clearness, it is very desirable that a tendency to separation along certain planes in a crystal, which has been developed by mechanical action, (gliding planes) or by chemical operations (schiller planes), should not be confounded with the original planes of least cohesion (cleavage planes). Nothing can be more incorrect or misleading than to speak of diallage as a variety of augite which exhibits an additional "cleavage"; or murchisonite as a variety of orthoclase which exhibits a new "cleavage." The induced structures in these minerals have nothing whatever in common with the original structure of the crystals, which gives rise to their characteristic tendency to break up parallel to certain planes, and is indicated by the term "cleavage."

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REVIEW.

Gems and Precious Stones of North America: by George Frederick Kunz. New York (*The Scientific Publishing Company*), 1890.

This work has an object which is clearly set forth by the author in his Introduction. It is not a complete treatise on Precious Stones, or on the Science of Mineralogy, but relates almost solely to those precious stones which have been found in North America. A brief general description and a series of recent analyses is given in each case: but the real object is to collect together all the known facts which bear upon the occurrence of precious stones in that part of the New World—such as the localities in which and the conditions under which they occur, the methods by which the search and mining for them are conducted, the value and amount of production; and to present these facts in a form which will render them available, not only for the mineralogist, miner, collector and jeweller, but also for the general public.

For the preparation of such a work the author is unusually well fitted, and has had excellent opportunities. His lengthened service with a large firm of jewellers has kept him in direct touch with precious stones as articles of commerce, and gives an eminently practical character and value to all his information; further he has visited and personally examined many of the localities which it is his province to describe: since 1882 he has been engaged as the writer of an annual report on the precious stones of the United States for the Division of Mining Statistics. Hence, as might have been anticipated, this volume includes a vast amount of useful information which is otherwise inaccessible both to the student and general public.

The minerals discussed are not only those which are regarded as precious, but all those which are used for decorative purposes, and include, for example, sodalite, meerschaum, fluor, and pyrites. There are also chapters on pearls, and on aboriginal lapidarian work in North America.

The work is creditable at once to the author and the publisher: it is printed with large type and on thick paper, while the eight coloured plates are themselves sufficient to make the volume a *livre de luxe*. For these plates no praise can be too high; such representations have never been seen before in any mineralogical treatise: especially worthy of notice are those of cyanite, garnet, tourmaline, microcline, emerald, beryl, amethyst, rutile in quartz, and pearl. There are also sixteen full-page illustrations, and twenty smaller ones in the text. L. F.

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THE MINERALOGICAL MAGAZINE
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No. 43. MARCH, 1891. Vol. IX.

Cassiterite, "Sparable Tin," from Cornwall.

By R. H. Solly, M.A., F.G.S.

[Read November 11th, 1890.]

DURING the last few years some fresh specimens of Sparable Tin have been raised from various mines in Cornwall; a description of this variety may therefore be of interest to the Society.

The value of this description of the new finds will perhaps be increased by combining with it an account of the specimens of Sparable Tin from different mines now to be found in our museums and private collections. Through the kindness of those gentlemen who own or have charge of these collections, I have been enabled to see and examine many of the interesting specimens which they contain.

The name "Sparable Tin" is peculiar to Cornwall, and has been given to this variety of Cassiterite on account of its so-called resemblance to the sparable nail of the cobbler.[1]

[1] Sparable may be the corruption of Sparrow-bill, so-called from its shape; *O.E.* Sparwa, a sparrow, literally 'a flutterer'; or the meaning of sparable nail may be simply that which spars or rivets, since *A.S.* 'sparriam' means to fasten or rivet.

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The crystals are always sharply pointed, having the ditetragonal pyramid z {321} largely developed together with an elongated striated prism.

In 1814 Mr. William Phillips published in the *Transactions of the Geological Society* a most valuable and interesting monograph on Oxyd of Tin, with eleven large plates of drawings of the different forms of Tin, and the accuracy of his work is proved by the fact that the angle which he found for the element of Cassiterite is accepted to-day.

On page 340 he says, "If it should hereafter more generally appear that some modifications of the primitive crystal of this substance are principally the production of particular districts, as I am led to suspect will be the case, might not an investigation of the nature and peculiarities of the veins and of the countries through which they pass tend to throw some light on the circumstances or laws by which the several modifications are produced: may not these circumstances be supposed in some degree to depend on the purity of the substance entering into combination with it? The Bohemian oxyd has not hitherto been observed to assume so great a diversity of crystalline forms as the Cornish, which, by the analysis of Klaproth already noticed, appears to be by far the most pure."

To this suggestion we are able to add to-day, that the slower the growth the greater is the modification of the form, and that minute impurities when not chemically combined have apparently no effect upon the crystalline structure, though when an isomorphous interchange of elements takes place a marked change is observed in the crystallographic element—but to the question, "What is the law which governs the different habits or modifications of crystals?" we can add nothing at the present time; all that we can do is to describe the modes of occurrence and the associated minerals for crystals of very similar combination, and leave the physicists of the future to deduce a law by the aid of such material. With this end in view I have brought together descriptions of the various specimens of the Sparable Tin of Cornwall.

Literature.

1814.	Phillips.	Trans. Geol. Soc. p. 336.
1822.	Haüy.	Traité de Minéralogie.
1823.	Phillips.	Mineralogy, third Edition, p. 250.
1852.	Miller.	Phillips' Mineralogy, p. 235.
1856.	Gadolin.	Verh. Russ. Min. Ges. p. 184.
1855.	Nordenskiöld.	Pogg. Ann. 101, p. 637.
1864.	Hessenberg.	Mineralogische Notizen, VI. p. 18.

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LITERATURE—*Continued.*

1877. Becke.	Min. Mitth. Vol. I. p. 248.
1882. Collins.	Min. Mag. Vol. IV. p. 1.
1889. Busz.	Zeits. f. Kryst. XV. p. 628.

TABLE OF FORMS.

Letter.	Symbol.	Author.	Locality.	Remarks.
c	001	Phillips	Cornwall	Very rare on Sparable Tin
a	100	,,	,,	Very often present ,,
m	110	,,	,,	Always present ,,
h	210	,,	,,	Not common ,,
r	320	,,	,,	Very often present ,,
r_1	430	,,	,,	Very common ,,
l	870	Busz	Huel Nancy	Very narrow ,,
k	14 13 0	Gadolin	Pitkaranta	Not observed ,,
e	101	Phillips	Cornwall	Always narrow ,,
w	501	,,	,,	Not observed ,,
x	114	Gadolin	Pitkaranta	,, ,,
y	335	Phillips	Cornwall	,, ,,
σ	223	Gadolin (s_1)	Pitkaranta	,, ,,
s	111	Phillips	Cornwall	Always present ,,
i	552	,,	,,	Very often present, very narrow
5 *p*	551	Gadolin	Pitkaranta	Not observed on Sparable Tin
n	661	Solly	Cornwall	Sometimes well developed ,,
η	771	Gadolin	Pitkaranta	Not observed ,,
p	12 12 1	Solly	Carn Brea and Tregurtha	Well developed ,,
q	18 18 1	,,	Huel Fanny	Largely developed ,,
ψ	120 120 1	,,	Cornwall	Sometimes well developed ,,
t	313	Phillips	Bohemia	Not observed ,,
z	321	,,	Cornwall	Characteristic form ,,
d	432	Solly	Maudlin mine	Narrow and rare ,,
ν	752	Becke	Huel Nancy	,, ,, ,,
θ	13 11 2	Solly	Mary Hutchins	Rare and narrow ,,
ξ	761	Hessenberg	Wheal Harris?	Not observed? ,,
ε	871	Busz	Cornwall	,, ? ,,
v	21 14 18	Gadolin	Pitkaranta	,, ,,
u	19 16 7	,,	,,	,, ,,
u_1	742	,,	,,	,, ,,
u_2	17 13 6	,,	,,	,, ,,
u_3	942	,,	,,	,, ,,
ζ	3 11 2	,,	,,	,, ,,
k_2	?	Phillips	Cornwall	?

The above list of forms, with the names of the authors who first observed them, will be found to differ from Becke's list, as he has ignored Phillips' work.

Miller has left out f_3, f_2 and k_2 of Phillips as forms not observed by him, though, if we accept his angles, f_3 would be the plane *η* (771) observed by Gadolin on crystals from Pitkaranta and Cornwall;

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Phillips.	Gadolin.
$f_3\ m = 8°54'$.	$\eta\ m = 8°32'$ calculated.

f_2 might be the n (661) observed by me on many crystals ;

Phillips.	Solly.
$f_2\ m = 10°40'$.	$n\ m = 9°56\frac{1}{2}'$ calculated.

From his figure 175, this should have the same indices as Miller's face i, but $i\ m = 22°49'$.

k_3 only appears in the third edition of Phillips' *Mineralogy*, and from his figure it should have the indices (28 14 3), as it lies in the zones [210, 001] and [$\bar{1}$10, 771] ; but the angles $k_2\ s = 43°40'$ and $k_2\ m = 8°55'$ are not those of (28 14 3).

Some of the Cornish crystals have minute planes lying either in the zone [430, 321] or [110, 321], but they are rounded or too dull to give any reliable measurements.

The planes $v\ u\ u_1\ u_2\ u_3$ observed by Gadolin on crystals from Pitkaranta are omitted by Nordenskiöld, and I have not found them on the Cornish crystals.

Becke in his list of forms has given i (552), but in his stereographic projection has placed it at the intersection of the zones [100,321] [110,111], which would give to the plane the indices (221), a form not yet observed.

In the zone [110,111] it will be noticed that the indices of the planes of the form $\{h\ h\ k\}$ observed on Sparable Tin are (661) (12 12 1) (18 18 1) (120 120 1), that is to say h is a multiple of 6.

The face (120 120 1) is often largely developed, and extends into the prism zone, being only inclined at 30′ to that zone.

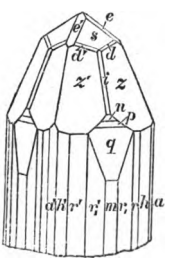

Fig. 1.

Fig. 1 exhibits a combined view of all the planes except c, ψ, ν, θ observed on crystals of Sparable Tin with a characteristic development.

Hemimorphism.

Is Cassiterite hemimorphic ?

Rutile, which is isomorphous with Cassiterite, is sometimes hemimorphically developed.

The more or less transparent crystals often have a dark crystal growth in the centre, the form of which is decidedly hemimorphic. See Fig. 2.

I hope to be able to show that it is so from the other varieties of Cassiterite in a future paper.

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Twins.

There is only one law, namely, the twin axis is normal to a face of the form {101}, the twin plane and face of composition being the same; the crystals are sometimes juxtaposition twins often repeated on the same face, or penetration twins consisting of two or more crystals twinned about different faces of the form {101}, or simple penetration twins. The last mode of twinning is rare: I have only observed it on crystals from the Dolcoath district, see Fig. 3; two Sparable Tin crystals having the face

Fig. 2.

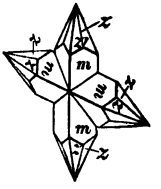

Fig. 3.

of composition the twin plane are fairly common in some mines, but Sparable Tin differs from other forms of Cassiterite in being nearly always simple.

Aggregations.

The mode of aggregation is very similar to that seen in crystals of tourmaline. A number of crystals are grown together very nearly parallel to their axis of tetragonal symmetry. This want of parallelism is perceived by the unequal angle between the *s* planes, which varies as much as 30′ in an apparently simple crystal. The prism planes also are seldom parallel.

Cleavage.

Miller gives *a* and *m*, not very distinct; *e*, traces. I have found that crystals of Sparable Tin often cleave with great facility parallel to only one of the *m* planes. This points to *m* being a face of union as well as a cleavage plane, and may be accounted for by aggregation.

Optical Characters.

Double refraction positive.

Refractive indices for red light:—

$\omega = 1{\cdot}9793$ $\epsilon = 2{\cdot}079$

Very slightly dichroic.

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Hardness.

The hardness for the massive brown and fibrous variety is only 6, while that of the brilliant black crystals is 7.

Specific Gravity.

The specific gravity varies a good deal.

Black crystals from Tipuani	...	7·021	(Forbes)
Colourless crystals from Tipuani	...	6·832	,,
Honey-yellow crystals from Oruro	...	6·704	,,
Very pure crystals from Carabuco	...	6·4	,,
Black Sparable Tin from Dolcoath	...	6·92	(Solly)

Chemical Composition.

Pure Cassiterite is not known. Dr. E. Ludwig found $SnO_2 = 98{\cdot}74\%$ $SiO_2 = 0{\cdot}19$ $Fe_2O_3 = 0{\cdot}12$ $CaO = 0{\cdot}41$ in a crystal from Schlackenwald, all other analyses show a small percentage of Ta, Ti, Mn, Si and Fe; this is probably due, as Dr. Ludwig thinks, to imperfect analysis and separation of impurities.

Elements.

The element adduced by Miller and agreeing with Phillips's angle has been repeatedly obtained from different crystals, and is therefore adopted in calculating the following angles:—

$001, 101 = 33°55'2''$ $\quad a : c = 1 : 0{\cdot}67247$

ah	= 26°34′	ze	= 67°35′	$zz_,$	= 20°54′	$z,z_{,,}$	= 61°41′
ar	= 33°41′	te	= 35°20′	$tt_,$	= 29°58′	$t,t_{,,}$	= 21°4′
$ar_,$	= 36°52′	de	= 59°15′	$dd_,$	= 13°58′	$d,d_{,,}$	= 59°57′
al	= 41°11′	νe	= 70°55′	$\nu\nu_,$	= 17°53′	$\nu,\nu_{,,}$	= 66°38′
ak	= 42°52′	θe	= 80°5′	$\theta\theta_,$	= 9°23′	$\theta,\theta_{,,}$	= 78°2′
am	= 45°	ξe	= 80°50′	$\xi\xi_,$	= 8°21′	$\xi,\xi_{,,}$	= 79°59′
		εe	= 82°2′	$\varepsilon\varepsilon_,$	= 9°31′	$\varepsilon,\varepsilon_{,,}$	= 81°25′

$m\psi$	= 0°30′	md	= 31°42′	$m\varepsilon$	= 8°50′
mq	= 3°20′	mt	= 58°41′	$m\xi$	= 10°10′
mp	= 5°	$ss_,$	= 58°18′	$m\theta$	= 11°
$m\eta$	= 6°32′	$ss_{,,}$	= 87°8′	$m\nu$	= 21°15′
mn	= 9°56′	nz	= 16°32′	$m\varepsilon$	= 25°
$m5p.$	= 11°52′	pz	= 20°34′	me	= 66°45′
mi	= 22°49′	qz	= 22°1′	ce	= 33°55′
$ms_{\frac{1}{4}}$	= 46°26′			cw	= 73°26′
$m\sigma$	= 57°37′			as	= 60°51′
$my_{\frac{1}{3}}$	= 60°17′			$at_,$	= 79°28′
mx	= 76·37′				

The following description of the various occurrences of Sparable Tin begins with the specimens of the Mary Hutchins mine in Devonshire, and moves westwards to the Land's End.

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Description of Specimens.

Mary Hutchins, Plympton, Devon.

Small black to brown crystals with sub-metallic to adamantine lustre, very much massed together with crystals of quartz. The crystals are often twinned. Twin plane e (101); the z planes large; small s; well developed m; narrow a and r; n (661) well developed, often rounded. This plane is new, its position was determined by the zones [321, 340] [231, 430].

$n\,m$ found 9°30′	Calculated 9°56′

Also a very small plane θ (13 11 2) lying in zones [010, 661] and [110, 321].

$\theta\,m$ found 10°30′	Calculated 11°

Callington, Cornwall.

The British Museum has a specimen labelled Callington with small light brown crystals with iron-stained pearlspar.

Forms s z and prism planes.

Maudlin mine, Lanlivery.

The Penzance Museum possesses a specimen from this mine, and the British Museum a number of loose crystals.

The crystals on the Penzance specimen have the forms z and s equally developed, prism long, m large and rough, narrow r, a small and bright, narrow e and very narrow i. A new plane d (432) lying in zones [321, 111] [010, 231].

$d\,s$ found 16°—17°	Calculated 16°54′
$d\,z_1$ found 14°—15°	Calculated 14°13′

The following minerals have been found in this mine: chlorite, chalcedony, chalybite, covelline, cronstedtite, fluor, garnet, jasper, melanterite, mispickel, opal, pyrites, pyrrhotine, scheelite, and wolfram.

St. Austell District.—Polgooth mine.

Minute crystals in compact chlorite.

z and m well developed, small e; associated with calcite, compact and semi-transparent. The other minerals found in the mine are amethyst, dolomite, erythrine, pyrites, smaltine, and copper pyrites.

Gavrigan Stream Works, St. Mewan.

These crystals are described by Phillips as being about the size of a common quill and exhibiting the faces $m\,z$ large, small $s\,e$, and c small and rare.

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Redruth District.—Huel Fanny.

Phillips has described these crystals. The Penzance Museum possesses a specimen. The crystals are of a light brown colour and very minute. The form q (18 18 1) is largely developed, sometimes very brilliant, giving good reflections but more often dull and rounded. s and z small, narrow i, prism well developed, m large, narrow a r_1 and h.

q m found 3° and 3°30′	Calculated 3°20′

The crystals were found in a shallow part of a copper vein, with redruthite and wolfram, sometimes imbedded in copper pyrites and coated with chlorite and quartz.

Carn Brea mine, Illogan.

This is a new occurrence. In form and appearance the crystals resemble those from Dolcoath, but are much more modified. The faces z and m large, small s, narrow r, and very narrow r_1.

One crystal is very interesting, as a new face p (12 12 1) is largely developed, being equal in size to the z planes. The angles obtained were very good.

z z_1 found 20°54′	Calculated 20°54′
m p found 4°58′	Calculated 5°0′

The crystals are associated with chlorite and quartz, calcite and brown oxide of iron.

Camborne District.—Dolcoath mine.

The crystals are often very fine, of a jet black colour shading into a dark brown with adamantine lustre.

The oldest specimen I have seen is one in the late Sir W. W. Smyth's collection found in 1859. Mr. J. M. Williams, of Caer-hays, Cornwall, has a specimen which was raised in 1861, and is associated with limpid fluor and chlorite.

About 1878 a number of fine specimens were raised from the 314 fathom level. Notable specimens are those belonging to Mr. C. C. Ross at Carne, the Penzance Museum, and also the British Museum.

Since 1884 some fine specimens similar in habit have been raised from the 260 fathom level. The Jermyn Street Museum and Cambridge University have specimens.

The matrix is invariably chlorite with quartz; I have never observed any tourmaline on the specimens, though Collins has found much acicular schorl in the tin stones which he described in the *Min. Journ.*, Vol. IV.

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p. 11; but these specimens were taken from the levels where no Sparable Tin has been found.

The forms are simple, z large, small s, well developed prism, m large, narrow $r_{\frac{1}{2}}$. The crystals are sometimes doubly terminated, often twinned, or sometimes consisting of four twinned crystals (Fig. 3).

Huel Harriett.

(This is a Sett adjoining Dolcoath on the South.)

Mr. C. C. Ross possesses a very fine specimen from this mine. The crystals are jet black with adamantine lustre. The forms are: z large, small s, prism deeply striated, r_1 large, narrow m and a. Hessenberg has described crystals from *Wheal Harris* (probably identical with this mine), on which he observed the new face ξ (761), but he says it is always deeply striated and curved, rarely giving good reflections.

The crystals are dark brown to black, banded in colour, associated with transparent fluor spar with a matrix of chlorite.

Huel Grenville.

The British Museum has a specimen. The crystals are on quartz with white talc. Forms s and z and prism plane; colour, dark brown.

Huel Nancy, Camborne.

The only specimen I have seen from this mine is in the Jermyn Street collection. The crystals are dark brown and very brilliant. Prism planes deeply striated, having a number of narrow planes $h\ m\ r_1\ l$. The planes s and z well developed; also a narrow plane ν (752) lying in zone $m\ z$ which had been observed by Becke on a Cornish crystal, locality unknown. The crystals are on chloritic schist with quartz and chlorite.

Gwinear District.—Wheal Tremayne.

These specimens are fairly numerous. The matrix is "peach" or crystallised chlorite and quartz. The crystals are of a light brown colour with good lustre, often closely aggregated together. Forms observed: z well developed, small s, narrow i, well developed n, prism well developed, m and r. The centre of the crystals is dark, giving the form of three crystals one upon the other.

St. Agnes District.

The British Museum has a specimen from St. Agnes district on chlorite, with quartz, fluor and copper pyrites. It is probably from Huel Park. Forms s and z, narrow, with prism planes; fine lustre; colour dark brown.

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Helstone.—Great Wheal Vor.

Nearly all collections contain specimens from this locality. Some are jet-black and polysynthetically grown together, others brown and often highly modified. The matrix is killas associated with chlorite, sometimes with very small limpid crystals of apatite with the forms $(10\bar{1})$ (201) (111). Blende, copper pyrites, mispickel, pyrites, and pearl spar have been found with the tin stone.

The black crystals in the Ross collection have the forms $s\ z\ r_1\ m\ l$, narrow i, polysynthetically grown together with chlorite. The brown crystals associated with apatite are very like the Tremayne crystals, having the same crystallographic and optical characters. The Jermyn Street Museum has a specimen from Metal Shaft raised in 1868.

Quartzose veinstone on massive tin stone.

Tregurtha Down mine, Marazion.

The first specimens were obtained from the shallow workings in 1864, but during 1889 well crystallised specimens have been raised from the 95 fathom level.

They resemble in habit and appearance those from Carn Brea. The forms $s\ z$ well developed, large r_1, small m, very bright p and narrow i.

The crystals are associated with quartz, chlorite, and small well developed crystals of albite, and they are often coated with impure kaolin.

Wheal Owles, St. Just.

Black isolated twinned group of crystals. Forms $s\ z$, narrow $i\ m$ and r. These crystals were given to me by Richard Boyns, Esq., of Wheal Owles.

Land's End.

Phillips describes some loose crystals "from the Land's End." Forms $s\ z$ and rounded $(h\ h\ k)$ largely developed.

It may be remarked from the above descriptions that Sparable Tin is always found in close proximity to an elvan; also that chlorite is always present, while tourmaline and topaz are nearly always absent. The only occurrence of apatite associated with Sparable Tin that I have seen is at Wheal Vor.

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Twins of Marcasite in regular disposition upon Cubes of Pyrites.

By C. O. Trechmann, Ph.D., F.G.S.

[Read November 11th, 1890.]

THE subject of this note derives interest less from its novelty than from the beautiful manner in which the intergrowth is exemplified in Nature. As Sadebeck[1] has shown, the intergrowth of marcasite and pyrites takes place according to two laws.

(1) The vertical axis of marcasite is parallel with a principal axis of pyrites; one of the two other principal axes of the latter being parallel with the combination edge *m* (110) ∞P : *c* (001) 0*P* of the former; or, in other words, the vertical and one lateral axis (*ab*) of marcasite coincide with two principal axes of pyrites.

(2) The vertical axis of marcasite is parallel with a principal axis of pyrites; the brachydiagonal axis is parallel with a diagonal axis of pyrites.

The first law appears to be the more general, and Sadebeck describes intergrowths where cubes of pyrites are disposed on marcasite, and also where twins of marcasite are disposed upon the cubical faces of pyrites, the twin planes of the former being parallel with the three faces of the cube. (See his Fig. 6, Pl. X.)

The present instance seems to be a more perfect development of the one observed by Sadebeck on crystals from Freiberg; it occurs on a specimen from Bredlar, near Brilon, in Westphalia, consisting of red iron ore upon the drusy surface of which marcasite crystals, together with a lesser number of cubes of pyrites, are dispersed.

The faces of the cubes of pyrites are deeply striated and curved by an indeterminable pentagonal dodecahedron, and the solid angles are occasionally replaced by minute octahedral faces. The marcasite crystals exhibit the forms :—

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[1] *Ueber die Krystallisation des Markasits und seine regelmässigen Verwachsungen mit Eisenkies, von A. Sadebeck, Ann. d. Phys. u. Chem. Erg. Bd.* 8, 625, 1878 (*Abstract : Zeitschr. f. Kryst.* 3, 626, 1879).

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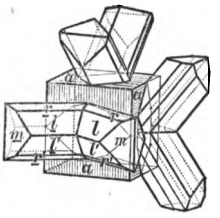

m	110	∞P
l	101	$\breve{P}\infty$
r	104	$\frac{1}{4}\breve{P}\infty$

and are frequently twinned according to the law: twin plane and composition face *m* (110) ∞P: forming contact twins. All the faces are very much curved and horizontally striated, and are not adapted for exact measurement. The form *r*, which gradually curves into *l*, was determined by approximate measurement,

$$r\,r'\ (\text{over } c) = 34°19' \text{ calc. } 33°0'$$

The disposition of the marcasite crystals upon the cubes of pyrites is such that each face of the cube carries a twin of marcasite by the above law of twinning, and according to Sadebeck's first law of intergrowth, in such a manner that the twin plane is perpendicular to the face of the cube and parallel with the striations upon its surface; thus, the outer prism faces (*m*) of each marcasite twin are parallel with the adjoining cubical faces, which are striated in the same direction as the prism faces, and the three composition faces of the twins are perpendicular to one another and correspond with the principal axial planes of the cube.

The accompanying figure, in parallel projection, is drawn as closely as possible from nature, and exhibits the marcasite twins, all of the same size, upon the three visible faces of the cube. The form *r* (104) $\frac{1}{4}\breve{P}\infty$ is however replaced in the drawing by the more frequently occurring form (103) $\frac{1}{3}\breve{P}\infty$.

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The Tetartohedrism of Ullmannite.

By H. A. Miers, M.A.

[Read November 11th, 1890.]

ALTHOUGH all the modes of hemihedrism possible in the cubic system have been found to occur among minerals, no mineral belonging to that system has yet been proved to be tetartohedral like sodium chlorate, and the nitrates of barium, strontium and lead.

There has, however, been some evidence in favour of the tetartohedral character of Ullmannite since the examination of the crystals from Lölling in Carinthia, and those from Sarrabus in Sardinia. The former were found by Zepharovich[1] to be distinctly tetrahedral in form and habit, the latter were found by Klein[2] to be distinctly pyritohedral. Zepharovich found the specific gravity of the Lölling Ullmannite to be 6·72, while Klein found that of the Sardinian crystals to be 6·803—6·883, and for this reason it was at first thought that the two occurrences might be different modifications of the antimono-sulphide of nickel; there was also considerable discrepancy between the two analyses.

But subsequently Klein and Jannasch[3] re-examined the Ullmannite from both localities, and found them to be identical both in composition and specific gravity. This necessitates one of two conclusions: either NiSbS is dimorphous, occurring both in a tetrahedral and also in a pyritohedral modification, or the mineral is tetartohedral. The latter is the more natural supposition; but it is not easy to understand why the crystals should be so distinctly tetrahedral in one locality and pyritohedral in the other, without combining the two characters in either.

I have had no opportunity of examining crystals from Lölling, but the description of Zepharovich makes it perfectly clear that they are not only tetrahedral but are also interpenetrating twins in which the mode of

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[1] *Lotos* (1870), 20, p. 4.

[2] *Neues Jahrbuch*, 1883 (1), p. 180.

[3] *Neues Jahrbuch*, 1887 (2), p. 169.

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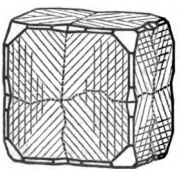
twinning restores a holohedral aspect to the tetrahedron as in the case of diamond.

Now, it is evident that this complementary twinning about the dodecahedral axes will simulate the holohedral character both in the tetrahedron and the pyritohedron; the latter is exemplified by the interpenetrating twins of iron pyrites.

It seemed probable, therefore, that a more careful examination might reveal traces of tetartohedrism and of twinning on the crystals from Sarrabus.

Here, as in the case of other opaque minerals, the surface striæ afford the most available clue to the compound nature of the crystals. In his first description of the cubes of Ullmannite from Sardinia, Klein mentions a well-marked striation similar to that of pyrites. In the second description he mentions that there is also to be seen here and there a striation parallel to the octahedron, and this was also observed by Seligmann.

The Sardinian specimens in the British Museum show the above characters, but the octahedral or diagonal striations on the cube faces exhibit the following peculiarities:—The faces are broken up into a number of distinct fields, upon some of which the striæ are parallel to one diagonal alone, while upon the remainder they are parallel to the other diagonal. It is evident then that each of these fields is a portion of a single crystal of at most tetrahedral symmetry, and that these crystals are twinned together about the dodecahedral axes.



The external appearance of the Sardinian cubes is represented, somewhat idealised, in the adjoining figure, which sufficiently explains the structure of the crystals. The diagonal striæ are always perpendicular to the edge of combination with the tetrahedron. The junction of the individuals is sometimes irregular, but is more usually parallel to the cube faces, so that the crystals appear to be built up of rectangular plates. At the points of junction the cube edges have a re-entrant angle formed by small striated faces of a triakis-octahedron, having indices near {27.27.1}, inclined to the tetrahedron at an angle of 37°—40°; these are often the only faces on the cube edges even when the latter appear to be truncated by the dodecahedron.

Since the pyritohedral striæ upon each cube face are only in one direction and traverse all the individuals, it follows that the crystals are not only tetartohedral and twinned about the dodecahedral axes, but that they consist of enantiomorphous individuals; thus in all respects resembling the

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right and left handed twin crystals of sodium chlorate, in which one individual of the twin crystals exerts a dextro-rotatory and the other a lævo-rotatory action on polarised light. If two identical crystals of Ullmannite were twinned together, the pyritohedral striæ would be reproduced parallel to all the edges on each cube face.

The tetartohedrism of Ullmannite does not make it necessary to remove the mineral from the group of isomorphous disulphides and arsenosulphides to which it is always referred, although so far as is known the remainder are pyritohedral, with the possible exception of gersdorffite and corynite. Dolomite, ilmenite and dioptase are analogous cases.

Becke[1] has suggested that the tetartohedrism of dolomite, which has been proved, both in its crystalline form and elastic properties,[2] to possess a lower degree of symmetry than calcite, is due to the lower symmetry of the molecule Ca Mg $(CO_3)_2$ as compared with the molecule Ca Ca $(CO_3)_2$.

But Ullmannite in its composition offers no such want of symmetry as compared with cobaltite, gersdorffite or corynite. It would be interesting should these three minerals also exhibit evidences of tetartohedrism, since their composition is less symmetrical than that of the disulphides or diarsenides. The specimens in the British Museum do not exhibit a tetartohedral character.

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[1] *Min. Mitth.* XI. p. 255.

[2] *W. Voigt. Ann. Phys. Chem.* XL. p. 642.

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A Student's Goniometer.

By H. A. Miers, M.A.

(*With Plates III., IV., and V.*)

[Read October 25th, 1887.]

THIS instrument, which was designed for use in the Crystallographic Laboratory of the City and Guilds of London Institute (Central Institution), is in its simplest form (Plate III.) a strong and inexpensive Wollaston Goniometer. It is, however, constructed in such a way that it may be converted into an instrument of greater precision (Plates IV. V.) by the simple addition of accessory parts to the apparatus of Plate III. without any previous alteration.

L is the graduated disc, and B the milled head by which it is turned; the vernier *v* is not the slender tongue of metal which is usual in such instruments, but is engraved upon a portion of the fixed disc V; and L is kept in continual contact with V by means of a circular steel spring inserted between B and the bearing of the axle. L has an inner lip by means of which it may be clamped by the screw C to the fixed disc V; the fine adjustment may then be effected by the slow motion screw D, which works against a spring and is fixed to V at a convenient angle on the side furthest from the observer.

The bearing of the axle is cast in a single piece with the metal crosspiece which supports the disc, and is made longer and more massive than is usual in similar instruments.

The only essentially new feature is to be found in the mounting and adjustment of the mirror; this part of the apparatus is carried by a strong brass tube A firmly screwed to the solid crosspiece. Upon A is a sliding tube E which can be clamped in any position by a split ring and screw shown at *e*; upon E and at right angles to it is fixed the tube F, in which slides a cylinder also clamped by a split ring and screw shown at *f*, but this cylinder has a pin fitting to a slot in F, so that it can only slide without rotation; the mirror is attached to it by the capstan-head screw H.

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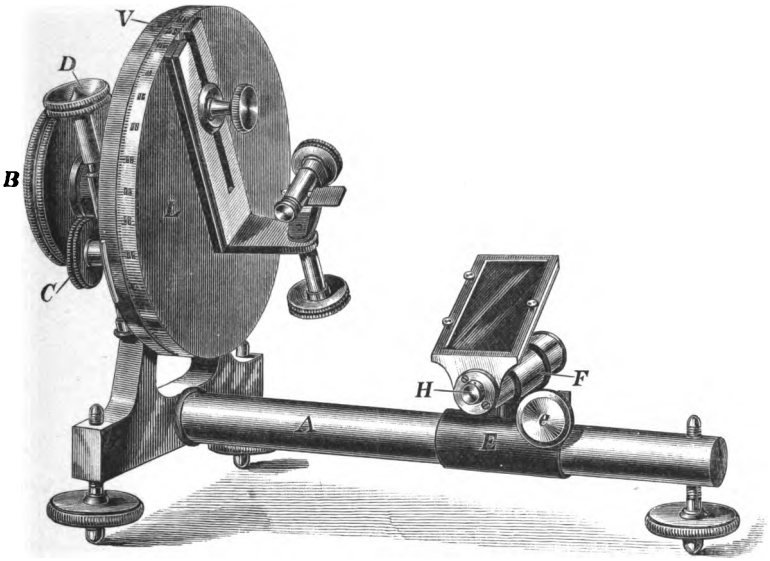

Fig. 1.

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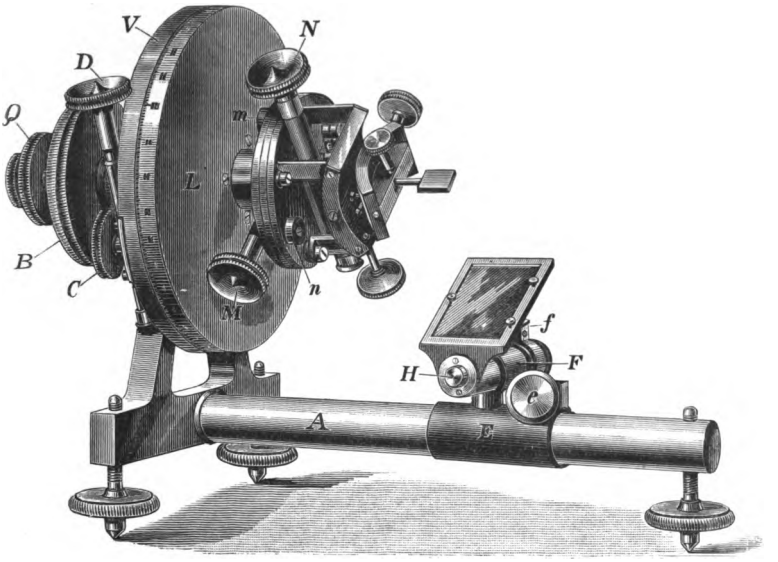

Fig. 2.

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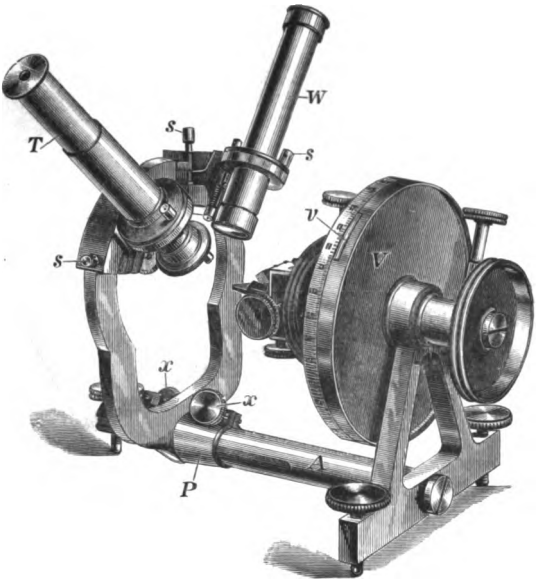

Fig. 3.

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It will be seen, therefore, that the mirror is capable of adjustment by two sliding movements along straight lines perpendicular to each other, namely, along the cylinders A and F, and by two movements of rotation about these lines.

To adjust the mirror the screw H is loosened, and the mirror is set parallel to the axis of the instrument in the usual way by means of a distant signal and a small plate with parallel faces mounted upon the goniometer; H is then clamped once for all, after which the other movements may be employed without disturbing this adjustment; the mirror may for instance be set at any desired inclination by rotating the tube E about A.

Plate IV. shows a modification of the same instrument in which the simple crystal holder and adjustments of Wollaston are replaced by the more complicated centring and adjusting apparatus devised by von Lang.

To receive this addition the axle of Plate III. is made hollow, so that nothing more is required than to remove the crystal adjustment-piece of Plate III. and to pass into the hollow axle a second axle attached to the adjustment-piece of Plate IV. The latter consists as usual of two traversing screws, M N, working at right angles to each other, for centring, and two tangent screws working parallel to them for adjustment of an edge.

In this instrument the centring movements are not, as is usual, effected by a slide which travels between straight guides, but the screws M N set in motion two plane discs which swing about pivots at *m* and *n*, and move in contact with one another.

The motion imparted to the discs by the screws M N is therefore not rectilinear, but a circular motion about *m* and *n* as centres. There is little or no practical inconvenience in this arrangement, and it is simpler in construction and stronger than the usual sliding motions between guides. The moving pieces are kept in true plane contact by spring nuts which pass through slots having the form of circular arcs described about *m* and *n* respectively as centres. Q is the milled head which turns the piece M N.

Finally, a third modification of the same instrument is shown in Plate V.

Here the levelling screw at the end of A having been unscrewed, the mirror is removed and replaced by a strong tube P, provided with two clamps *x x*, which slides on to A in place of E. This tube carries a telescope T and collimator W, attached to supports which slide upon opposite sides of a solid vertical circular arc; upon this they may be set at any desired inclinations by means of screw clamps on their inner sides;

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s s s are adjustment screws, by which the telescope and collimator are brought into the same vertical plane and directed towards the axis of the instrument.

This Goniometer has been constructed by Messrs. Troughton and Simms, of New Charlton, whose circles are, as is well known, divided with great accuracy.

The instrument of Plates III., IV. may be used with a horizontal slit placed in front of a window at a distance greater than 10 feet from the goniometer, as a distant bright signal. Prof. Miller originally recommended the employment of a separate faint signal which is to be seen reflected in the mirror, while the bright signal is observed by reflection in the crystal. I have found it advisable to use only one bright signal to supply both the image in the mirror and that in the crystal face.

To bring the two images into coincidence it is only necessary to introduce before the mirror a small card screen of such a height that it can intercept all the light which falls from the slit upon the mirror, but not the light which falls upon the crystal; if the screen is then moved laterally until it cuts off half or more of the image in the mirror, the adjustable image seen in the crystal face may easily be set with accuracy so as to form an exact prolongation of the remaining portion of the fixed image seen in the mirror; any desired amount of the latter can be cut off by moving the card screen.

A still more convenient signal is that recommended by Prof. Mallard; a small slit placed at its focus behind a large lens of about 5 inches focal length which stands close to the goniometer and is illuminated by a lamp.

To fix crystals to the holder nothing is more convenient than a mixture of beeswax and pitch, which may be fused together in different proportions to form a cement of any desired consistency; for this purpose a mixture in the proportion of two parts by weight of wax to one of pitch is generally suitable.

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On an Eclogite from Loch Duich.

By J. J. H. Teall, M.A., F.R.S., F.G.S.

(By permission of the Director General of the Geological Survey.)

[Read January 27th, 1891.]

THE existence in the British Isles of a rock essentially composed of garnet and omphacite, and answering therefore to Hauy's[1] definition of eclogite, does not appear to have been hitherto recorded.[2]

The following description of such a rock from Totig Ferry, Loch Duich, is therefore of some interest. The specimen was collected by the Director General, who informs me that he believes it to be a part of the Archæan gneiss which in the region of Loch Alsh and Loch Carron has been thrust bodily from the east over the Torridon sandstone.[3]

The rock is of a dull green colour, and contains numerous reddish-brown garnets. Under the microscope the principal constituents are seen to be garnet and omphacite—a pale green pyroxene without any definite crystalline form. Green hornblende, plagioclase, rutile, iron-ores, quartz, and epidote occur as accessories.

Garnet.—This mineral is of the common almandine-type. It occurs as idiomorphic crystals, and as aggregates of more or less rounded grains. Rutile and iron-ores are present in it as inclusions. A narrow zone of hornblende-substance frequently surrounds the garnets, and this is especially the case when omphacite and garnet are not separated by any other mineral. The hornblende-substance also penetrates the garnets along cracks. Irregular patches of epidote are sometimes seen in the interior of the garnets, as if replacing portions of their substance.

Omphacite.—This is a pale-green mineral having the cleavage and optical characters of pyroxene, but without definite crystalline form. It

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[1] *Traité de Minéralogie.* 2nd. ed. Paris, 1882. T. II. p. 456, and T. IV. p. 548.

[2] Prof. Bonney has described a rock essentially composed of garnet and hornblende under the name of hornblende-eclogite. *Quart. Journ. Geol. Soc.* Vol. XXXVI. (1880) p. 106.

[3] The description is based on a specimen (No. 1805) in the collection of the Geological Survey.

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is very faintly pleochroic in greenish and yellowish tints. Hornblende and felspar are sometimes intimately intergrown with omphacite. Thus hornblende, as already pointed out, forms a narrow zone separating garnet and omphacite. It also replaces omphacite more or less in certain parts of the rock. The intergrowths of omphacite and felspar are of a micro-pegmatitic character, and in some parts of the slide they play the *rôle* of groundmass. That the ferro-magnesian constituent of these micro-pegmatitic aggregates is omphacite and not hornblende is proved by the fact that where the aggregates are in contact with omphacite it extinguishes simultaneously with that mineral, and resembles it in all other respects.[1]

Hornblende.—The mode of occurrence of this constituent has been sufficiently described above. The pleochroism is as follows :

α pale yellowish brown.
β deep rich green.
γ bluish green.

Felspar.—Colourless water-clear felspar, showing one and sometimes two sets of twin lamellæ, is present in the rock in small quantity. Its mode of occurrence is remarkable. In thin section it appears in small irregular and isolated patches between the larger constituents. Under crossed nicols these isolated or apparently isolated patches give uniform extinction over considerable areas. It appears, therefore, that felspar by itself or intergrown with omphacite plays the *rôle* of groundmass in portions of the rock.

Rutile.—This mineral is present in the form of deep yellowish brown grains and slender yellow prisms. The grains are often associated with iron ores, which, however, occur very sparingly in the rock. *Quartz* is rare, and probably a secondary product. *Epidote* is also rare. Its mode of occurrence has already been described in speaking of garnet.

[1] Becke describes similar intergrowths of hornblende and felspar in an eclogite from Altenburg. Tscherm. Min. Mitth., Neue Folge, B. IV. p. 318.

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On a Micro-granite containing Riebeckite from Ailsa Craig.

By J. J. H. Teall, M.A., F.R.S., F.G.S.

(By permission of the Director General of the Geological Survey.)

[Read January 27th, 1891.]

RIEBECKITE was first described by Sauer[1] in 1888. The type-mineral occurs in granite from Socotra collected by Dr. E. Riebeck.

In the same year Harker[2] identified the peculiar blue hornblende occurring in the quartz-porphyry of Mynydd Mawr with the mineral described by Sauer, and in the following year two fresh localities were given for this mineral by Le Verrier[3] and Lacroix.[4] The last mentioned observer has also shown that crocidolite must be referred to the same group of hornblendes.

The object of this communication is to place on record the occurrence of riebeckite in the so-called syenite of Ailsa Craig, the small island which stands at the entrance to the Firth of Clyde. The following description of this island is taken from the *Memoirs of the Geological Survey* (Explanation of Sheet 7, page 12):—

"Ailsa Craig is an oval-shaped island, lying ten miles west from Girvan. Its extreme height is 1,113 feet, its longer (or N. and S.) diameter is about 1,500 yards, and its shorter (or E. and W.) diameter from 1,000 to 1,250 yards. It rises nearly vertically from the sea, on all sides except the east. There a triangular patch of low shingly ground intervenes between the base of the steep eastern declivity of the island and the waves. The Craig consists of a gray fine-grained syenite, which, on the

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[1] *Ueber Riebeckit, ein neues Glied der Hornbledegruppe. Zeitschr. d. deutsch. geol. Gesell.* Band XL. (1888), p. 138.

[2] *Additional note on the blue hornblende of Mynydd Mawr. Geol. Mag., Decade* III., Vol. V. (1888), p. 455.

[3] *Sur une venue de granulite à riebeckite de Corse. Comptes Rendus*, CIX. p. 38.

[4] *Sur une roche à amphibole sodique (riebeckite), astrophyllite, pyrochlore, et zircon du Colorado. Comptes Rendus*, CIX. p. 39.

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southern and western precipices, shows a system of close, parallel, vertical joints, by which a columnar aspect is given to the rock. Though no Silurian strata are visible here, there is every reason to believe that this syenitic mass rises among rocks of that age, resembling in this respect, as well as to some extent also in petrographical character, some of the crystalline rocks which rise through the Silurian strata of the south of Ayrshire. Dykes of dolerite run in a north-westerly direction through the syenite."

The syenite, which may perhaps be more appropriately termed a micro-granite, although the point is not of much importance, is of a light greenish gray colour, and fine grained, almost felsitic, in texture. Small felspars may occasionally be seen, and the surface is spotted with irregular blotches of a dark blue colour. When examined with a hand-lens the main mass of the rock is seen to be finely crystalline, and both felspar and quartz may be recognised. Nothing definite can be made out as to the nature of the dark blue patches beyond the fact that they are aggregates of a dark-coloured mineral and the main mass of the rock.

In thin section under the microscope the essential constituents are seen to be felspar, quartz and riebeckite. Zircon has been detected in the powder of the rock.

The riebeckite occurs in small extremely irregular patches wedged in between the idiomorphic felspars of the groundmass. Several of these small patches usually occur together; and, although apparently detached, they are similarly orientated. The mineral therefore forms spongy ophitic masses, the inter-spaces being occupied by felspar. Crystalline form is not generally recognisable, but cross-sections showing the cleavages of hornblende may be seen. The absorption is very great, so that it is by no means easy to investigate the optical characters of the mineral. These are best made out in the feather-edges of oblique sections and in slides made from the powdered rock. The mineral is strongly pleochroic in greenish or yellowish brown and deep blue tints.

α and β=deep blue.
γ=yellowish or greenish brown.

All that can be definitely ascertained with reference to the extinction is that the angle is very small. The fact that the greatest axis of elasticity (α) is the one which is most nearly coincident with the vertical axis can be readily observed in the small fragments obtained by breaking up the rock. This is the most characteristic feature of riebeckite, and the one which distinguishes it from all other hornblendes. It is this which makes

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riebeckite, amongst the hornblendes, the equivalent of ægirine, amongst the pyroxenes.

The larger felspars, which give a micro-porphyritic character to the rock, occur in crystals and fragments. Rectangular sections with straight extinction are not uncommon, and binary twins may occasionally be observed. The small felspars of the groundmass make up a large portion of the rock. They give lath-shaped sections, and, like the larger felspars, are either simple individuals or binary twins. In the slides prepared from the powder of the rock rhomboidal flakes showing the emergence of a positive bisectrix normal to the flake (M flakes) and giving an extinction of about 10° in the positive direction have been observed. These facts point to the conclusion that the felspar is a soda-orthoclase.

The quartz is interstitial or ophitic. It fills the spaces between the idiomorphic felspars.

Only two or three zircons have been observed. They are perfect crystals of the simple type showing the forms {110} and {111}.

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On Occurrences of Riebeckite in Britain.

By GRENVILLE A. J. COLE, F.G.S.

Professor of Geology in the Royal College of Science, Dublin.

[Read January 27th, 1891.]

IN the summer of 1890, in the company of Mr. L. W. Fulcher, I again visited Mynydd Mawr, on the west of the Snowdon area, in the hope of obtaining specimens of Riebeckite larger than those on which Mr. Harker[1] and Professor Bonney[2] based their observations in 1888, when they independently pointed out the occurrence of this mineral for the first time in the British Isles. Previous traverses of the dome-shaped mass had shown how uniform in structure and how minutely crystalline the rock of Mynydd Mawr was over all its surface; we accordingly examined the columnar cliffs on the north and west, paying especial attention to the great western hollow, where denudation allows one to stand almost in the centre of the intrusive neck. But even here we were somewhat disappointed, and our specimens are only slightly coarser in grain than those studied with such striking results by Professor Bonney.

In section, however, the blue colour of the amphibole is seen in these new specimens with greater clearness than heretofore. The streaky patches formed by the mineral are two to three millimetres across, and in one case, taken from a loose block fallen from the cliff, we have the remains of a single crystal at least two millimetres in length. The axis-colours, changing from the characteristic intense black-blue to a rich yellow-brown, are particularly striking in these large examples.

Though the groundmass of the "felsite" of Mynydd Mawr has undergone secondary devitrification, and at one time must have approached the glassy condition so prevalent in Wales among rocks of Bala age, yet abundant porphyritic crystals occur in these central masses. Orthoclase is predominant, with some quartz, which has in part developed with its proper outlines, as happens in so many rocks intermediate between granite and

[1] "On the Blue Hornblende of Mynydd Mawr." *Geol. Mag.*, 1888, p. 455.

[2] *Mineralogical Magazine*, Vol. VIII., pp. 103 and 169. For analysis of Riebeckite see *ibid.* p. 167.

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the glassy rhyolites. The quartz granules of the groundmass, in their association with the duller felspathic areas, suggest the commencement of a micro-pegmatitic structure. Throughout this groundwork of material imperfectly differentiated and developed, the patches of soda-amphibole seem an appropriate and original constituent. Their mode of occurrence recalls the groups of streaky biotite characteristic of the spherulitic and micro-pegmatitic soda-eurites.

The development of all the minerals seems, however, to have been hurried, doubtless owing to the comparatively short time during which highly silicated lavas remain fluid. Hence the amphibole, while surrounding in places well formed crystals of felspar, and tending to produce an ophitic structure, has been interfered with by the development of quartz and felspar in the glassy groundmass round it, and has thus only rarely arrived at any recognisable crystalline form. But for the inclusions of idiomorphic orthoclase, which run into the amphibole from the surrounding groundmass, it might have been urged that these ophitic areas were relics of large crystals which had been eaten into on all sides by the glass.

In a prior consolidation, however, when the porphyritic crystals were produced, similar amphibole arose under conditions that would have rendered the rock granitic. For we find in one of the thin sections an interesting "glomeroporphyritic"[1] group, consisting of quartz, orthoclase, and the richly coloured riebeckite. The material is unfortunately insufficient to afford evidence of the order of succession of these minerals in the granitic consolidation. The quartz of this group has been corroded by the groundmass, and the riebeckite seems also to have suffered.

The evidence of these central specimens, if I read it rightly, is that the rock of Mynydd Mawr reached its present position, in what seems to be a volcanic neck more than a mile in diameter, as a soda-glass containing porphyritic crystals and groups of crystals; these were attacked as long as the mass remained fluid, but they suffered less than is common in actual lava flows. While consolidating as a pitchstone on its margins, where it abuts against the altered slates, the mass in its more central parts tended to become micro-pegmatitic, after the manner of the eurite of Cader Idris, but without spherulitic aggregation. At this stage the riebeckite developed, filling up interstices and forming in many places continuous ophitic crystals. The cause of its crystallisation at so late a stage is probably to be found in its easy fusibility, to which attention has

[1] Judd, *Quart. Journ. Geol. Soc.* Vol. XLII. (1886), p. 71.

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been called by Mr. Harker.[1] With 35 per cent. or so of iron oxides, 10 per cent. of alkalies, and a striking deficiency of magnesia, riebeckite would remain far longer than ordinary amphiboles in the condition of a molten glass.

That Prof. Bonney has foreseen some of these conclusions, despite his view that the mineral is of secondary origin in the great mass of the rock, is clear from the concluding passages of his paper.[2]

While I was considering these specimens from Mynydd Mawr, I received from Mr. P. F. Kendall, F.G.S., of Stockport, a pebble of eurite from the drift of the North of England. Both Prof. Sollas, who kindly examined it, and myself were satisfied that the broad dark patches in the yellow groundmass of this rock represented a blue amphibole, and hence probably a variety rich in soda. Mr. Kendall had been independently struck with the same idea, and had consequently compared his specimens with the rock of Mynydd Mawr. He has allowed me to have sections prepared of two pebbles, one collected in the Isle of Man, the other, curiously enough, from Moel-y-Tryfan, close to the western face of Mynydd Mawr. But, apart from the presence of the interesting slate-blue amphibole, the rock has no close resemblance to any now exposed at Mynydd Mawr. Mr. Harker[3] has referred, however, to pebbles of the Mynydd Mawr rock in the drift of the neighbourhood; and it is quite possible that both these soda-eurites, from different sources, may have been brought together during the formation of the glacial beds. Suffice it that Mr. Kendall's specimens, as he himself points out, have more in common with one another, though from such different localities, than they have with the rock of Mynydd Mawr.

Thus in the specimen from the drift on Moel-y-Tryfan the structure is that of the coarser types of eurite. We have a beautifully developed micro-pegmatitic, but not spherulitic, groundmass; and, intimately associated with this, ophitic crystals of blue-green amphibole. At times the amphibole has developed soon after the separation of idiomorphic felspar, and has thus produced a patch in the rock from which quartz is locally excluded. In other places micro-pegmatitic growths of quartz and orthoclase have been filled in, and in part surrounded, by ophitic amphibole. This micro-pegmatite occurs in straggling patches, as in much of the well-known enstatite-diorite of Penmaenmawr; if we may regard these as

[1] *Geol. Mag.* 1888, p. 455.
[2] *Min. Mag.* Vol. VIII. p. 107.
[3] *Geol. Mag.* 1888, p. 224.

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original products of consolidation, as I am inclined to do, areas remained between them in which less stable felspars were afterwards developed. These have decomposed to a dusky brown tint, leaving the micro-pegmatitic patches, together with the amphibole, remarkably fresh and clear. It would appear, indeed, as if the micro-pegmatite, and also the porphyritic crystals of quartz and orthoclase, represented a previous attempt at crystallisation during quiet conditions of consolidation; the material was, however, broken up and set in motion, and the subsequent devitrification of the interstitial glass has given us the dusky areas. The characteristic amphibole appears also in the latter, but in the form of minute rods and granules.

The porphyritic crystals of quartz contain brown glass-enclosures, often with bubbles, and bear very little resemblance to the quartz of old granitic rocks. The amphibole occurs here and there in fair-sized crystals, but still with a tendency to ophitic inclusion of felspar at the edges, and with a consequent lack of idiomorphic outline. But such sections are much more easily studied than those of the same mineral at Mynydd Mawr, and the agreement of the optical characters of this amphibole with Sauer's riebeckite can be satisfactorily demonstrated. The approximate coincidence of the direction of greatest elasticity with that of the principal axis of the crystal would remove the amphiboles of Mr. Kendall's specimens from the ordinary well-known types; the intensity of the pleochroism, and the fact that indigo-blue rather than blue-violet axis-colours appear, show, moreover, at once that we are dealing with a mineral less familiar even than glaucophane.

I need say nothing of the pebble from the Isle of Man, beyond that it repeats in a remarkable degree the characters of that from Moel-y-Tryfan. In this respect the microscopic evidence only bears out Mr. Kendall's accurate judgment in the field; and geologists will be glad to learn to what locality he may be able to trace these interesting erratics.

The nature of the riebeckite crystals in the specimens from the drift has not permitted me to make very exact determinations of their extinctions; the sponge-like structure of so many, owing to the multitude of ophitic enclosures, renders the observer cautious in judging of their orientation. But in those examples where I have felt more secure, I have read off a larger angle between c and a than is recorded for typical riebeckite. I have thus obtained 6°0′, 8°5′, 9°45′ and 8°0′. It is, however, reasonable to suppose that variations towards normal amphibole will be found in this peculiar group of forms, just as among soda-pyroxenes the extinctions depart widely from the small angle of strictly defined ægirine and acmite.

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It will be interesting to learn, as our knowledge of soda-amphiboles increases, whether riebeckite is typical of rocks of igneous origin, while glaucophane arises in regions of pressure-metamorphism; or whether the peculiar relation of the axes of elasticity to those of form depends, as at present appears, purely on chemical constitution, viz. on the presence or absence of iron oxide.

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On a rapid method for the accurate recognition of sulphides, arsenides, antimonides, and double compounds of these bodies with metals.

By Charles A. Burghardt, Ph.D., &c.

[Read January 27th, 1891.]

THE process to be described has been applied to the minerals mentioned below, but I have no doubt that all similarly constituted minerals will also be easily recognised by the method.

I am quite sure that all mineralogists have experienced much annoyance and difficulty in obtaining really satisfactory results with the ordinary blow-pipe reactions in regard to some of the compounds of arsenic, antimony, and sulphur with metals, particularly in the separation of the metal or metals from the above-mentioned elements. In order to obtain the metal the assay requires a most careful and tedious roasting on charcoal in the *oxidising flame* of the blow-pipe, in order to volatilise away the sulphur, arsenic, or antimony. When this roasting is complete the residue (oxide) is mixed with either sodium carbonate, or that salt and cyanide of potassium, and fused for a considerable time on charcoal in the reducing flame in order to obtain a bead of the metal. Sometimes borax is used to eliminate a metal from a mixed oxide residue, dissolving one oxide and leaving the other. If the oxides left after the oxidising process above-mentioned are not soluble in borax, then the bead which is obtained in the subsequent reducing process is an alloy, and practically useless as a means of recognition of the metals entering into its composition. Having often been disappointed with the results obtained by the above-mentioned blow-pipe processes, I determined to find, if possible, a more rapid and certain method of analysis of minerals.

The apparatus required is that which all mineralogists have been in the habit of using for a long period, viz.

1st. Small porcelain crucibles.

2nd. Test-tubes.

3rd. A small platinum basin and a platinum crucible.

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4th. A platinum spoon made rather deep, something like a platinum crucible with a handle.

5th. Hard-glass tubing, closed at one end and about 4in. long; a cork is placed in the open end, with a hole bored through it, and a hard-glass tube of small bore passed just through the cork. The straight piece outside the cork is bent either *twice* at right angles (if required to pass vapours into water or solution), or *once* at right angles, and drawn out to a fine nozzle if required to test for arseniuretted or antimoniuretted hydrogen.

6th. A Bunsen burner of the ordinary type, or a spirit-lamp.

7th. Funnels, beakers, porcelain evaporating basins, stir-rods, &c. &c., and small pieces of clean sheet-iron and sheet-copper.

Reagents.	
Ammonium nitrate	(solid)
Sodium nitrate	,,
Potassium bi-sulphate	,,
Metallic zinc	,,
Hydrochloric acid	(solution)
Potassium ferrocyanide	,,
Potassium ferricyanide	,,
Ammonia-liquor	,,
Caustic soda	,,
Silver nitrate	,,
Stannous chloride	,,
Bi-chromate of potassium	,,

All the above reagents can be carried about in the *dry solid* condition for travelling, except the hydrochloric acid and the ammonia. With regard to the latter it can be carried in the form of solid ammonium carbonate or ammonium sulphate; and the ammonia liberated from the respective salts in the usual manner, and passed either into the solution to be tested or else into water. I cannot at present give as easy a way of producing hydrochloric acid when it is wanted from dry materials, but think that it could be prepared in sufficient quantity by heating together in a glass tube (with delivery tube attached as described above) a mixture of potassium or sodium bi-sulphate and sodium chloride. Hydrochloric acid gas would then be liberated. Nitric acid is not required in this method at all.

Having thus briefly touched upon the present method of the treatment by the blowpipe of the minerals containing volatile elements, I will at once proceed to describe the method proposed by myself to attain the

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same object. The oxidising reagent I use is pure *crystallised ammonium nitrate*. This salt, on being heated to about 250° C., decomposes, intumesces, and the products of its decomposition are nitrous oxide (N_2O) and water. *Thus the products are both gases, and nothing remains behind, which is certainly a very great consideration.* The *nitrous oxide*, at the high temperature used, rapidly gives up its *oxygen* to any element having an affinity for that gas, and *oxidises* it, so that finally the principal decomposition products of the original ammonium nitrate which are evolved as gases are nitrogen and vapour of water. The *modus operandi* is exceedingly simple. The mineral to be tested is crushed up and powdered into an exceedingly fine powder, a platinum or porcelain crucible is taken and filled to about one-fourth of its bulk with coarsely crushed ammonium nitrate crystals, then upon this about 0·5 gram of the finely powdered mineral is placed, and the crucible and contents held with a pair of tongs over the Bunsen lamp, just in the flame. A violent reaction is at once set up, and care must be taken to withdraw the crucible from time to time from the lamp in order to avoid loss by boiling over the sides. Sometimes it is necessary to add some more ammonium nitrate crystals to the partially cooled "melt" in the crucible and heat again in order to complete the reaction. *An excess of ammonium nitrate cannot possibly do any harm, and it ensures success.*

The crucible having been allowed to cool, the contents are extracted with water and the solution separated from the insoluble matter. During the fusion of the mineral in the crucible, characteristic colours of various metallic salts are most distinctly observed, occasionally, therefore, the operator must watch this fusion closely. The fusion and lixiviation of the melt only occupy a minute or two when one has attained some experience, but the whole analysis need not exceed fifteen minutes even in complicated compounds. When melting the mineral in a glass tube with the ammonium nitrate and passing the products of combustion into water, care must be taken to carefully dry the ammonium nitrate in a water oven previous to use, as it rapidly absorbs moisture from the air, and the water thus evolved in the fusion tube would cause the hot glass to crack. The thoroughly dried ammonium nitrate is conveniently kept in a *well stoppered* bottle.

Sulphides of Arsenic.

Orpiment (As_2S_3).

Realgar (AsS).

Fused in glass fusion tube with tube bent twice at right angles, the open end of the delivery tube dipping into water. Sulphuric acid was found in

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the water in distinct quantity by the usual barium chloride test; therefore the mineral was a *sulphide*. In the fusion tube was a slightly coloured solid residue which could be eventually completely dissolved in boiling water; it gave the reaction for *arsenic acid* (with nitrate of silver) and all the other reactions for arsenic; mirror on being treated with metallic zinc and acid potassium sulphate, and the arseniuretted hydrogen, decomposed into metallic arsenic by heating the hard-glass delivery tube to redness. *The mineral was therefore arsenic sulphide.*

Antimony Sulphide.

Stibnite (Sb_2S_3).

Fused in the same kind of apparatus as that used for the sulphides of arsenic, yielded sulphuric acid in the water and a mixture of Sb_2O_3 and Sb_2O_5. A little sulphuric acid was also detected in the water which had been used to boil the residue in the fusion tube. On adding a solution of potassium bisulphate to the residue in the fusion tube, and a piece of pure metallic zinc, antimoniuretted hydrogen was at once evolved, and a mirror of metallic antimony obtained on heating the delivery tube to redness. Other tests applied proved this mirror to be really antimony. The mineral did not give reactions for any other element likely to be present, hence it was *sulphide of antimony.*

If it is suspected that both arsenic and antimony are present in a mineral in large amount, they can be easily separated from each other by substituting *sodium nitrate* for ammonium nitrate, when a compound of antimony and sodium, insoluble in cold water, is obtained (antimonate of sodium), whilst the arsenic forms arsenite and arsenate of sodium, both of which are soluble in cold water after standing some time.

Löllingite.

$Fe\ As_2$.

Fused with ammonium nitrate in a platinum crucible or porcelain crucible. Melt red-coloured. Dissolved in hot water gave the reactions for arsenious and arsenic acid with silver nitrate and the usual arsenic reactions. The insoluble residue gave the reactions for iron. The mineral was therefore an *arsenide of iron.*

Proustite.

Ag_3AsS_3.

Fused in the same manner as the last-mentioned mineral, yielded a *black* residue containing arsenic oxide (this residue will be the subject of special examination, as it is peculiar). The melt was treated to separate

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the black residue. A solution of silver sulphate was obtained, which gave the characteristic reactions for silver and sulphuric acid. The black residue was treated with the acid-potassium-sulphate solution and metallic zinc, and arsenic was detected in the usual manner. The solution in water also gave the characteristic reaction for arsenic acid with silver nitrate. All the silver of the proustite was converted into sulphate, on account of the high percentage of sulphur in this mineral. The mineral was therefore a *sulph-arsenite of silver*.

Pyrargyrite.

$Ag_3\ Sb\ S_3$.

Treated in the same way as the preceding mineral, sulphate of silver was obtained in solution in water, and insoluble antimonious and antimonic oxide (Sb_2O_3 and Sb_2O_5) remained as a residue. The antimony reactions were obtained, and only silver and sulphuric acid detected, consequently the mineral was a *silver sulph-antimonite*.

Argentite.

Ag_2S.

On treating this mineral in the same manner as pyrargyrite, sulphate of silver was produced in small amount, owing to the small percentage of sulphur present in argentite. On adding a small quantity of "flowers of sulphur" to the powdered mineral, and then fusing the mixture with the ammonium nitrate, a larger quantity of silver sulphate was obtained. The solution gave the reactions for silver and sulphuric acid only, consequently the mineral was a *sulphide of silver*.

Iron-Pyrites.

Marcasite. Pyrites. FeS_2.

Fused as above gave a reddish brown residue of ferric oxide (Fe_2O_3) and a brown solution in water, which gave the characteristic reaction for *ferric*-salts with potassium ferrocyanide solution, and also the reaction for sulphuric acid. The mineral was therefore *sulphide of iron*.

Galena.

PbS.

Gave a *white* residue (insoluble in water) of *lead sulphate*, and nothing in solution. The residue was dissolved in hot hydrochloric acid, when a portion of the solution gave a white precipitate (of barium sulphate) on the addition of a solution of barium nitrate, and another portion of the hydrochloric acid solution, on being neutralised with sodium carbonate

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and boiled with a solution of potassium bichromate, gave the characteristic yellow lead chromate reaction. The white lead sulphate residue mentioned above, on being treated *directly* with the solution of potassium bichromate, also gave the lead chromate reaction. The mineral was therefore a *sulphide of lead.*

Copper-glance (*Redruthite*).

Cu_2S.

Gave a *blue* melt *whilst hot*, which became brown on cooling. The melt dissolved completely in water into a blue solution, which gave the usual reactions for copper and sulphuric acid. The mineral was therefore a *sulphide of copper.*

Bismuth-glance.

Bi_2S_3.

The melt was brown when cold. A solution of *sulphate of bismuth* was obtained, which gave the reactions for bismuth and sulphuric acid. An excellent and delicate reaction for bismuth is that which was shown to me by Professor Bunsen at Heidelberg 21 years ago, which I have never yet seen described in any work on qualitative analysis. In applying it to the solution of the melt first add a slight excess of caustic soda solution to it, when a *white* precipitate of hydrated bismuthic oxide (Bi_2O_3 H_2O) is obtained. In another vessel add an excess of caustic soda solution to a solution of stannous chloride, when a white precipitate of hydrated stannous oxide (SnO H_2O) falls out, but immediately re-dissolves in the excess of caustic soda. The bismuth precipitate obtained as above is washed into a white basin and a portion of the caustic stannous solution poured upon it and well stirred with it, when very soon a dense *black* precipitate is seen in the white basin, this precipitate being an oxide of bismuth Bi_2O_2, formed by the reduction of the Bi_2O_3 through the SnO.

Millerite.

Ni S (with Co and Fe).

Gave a *green* solution of sulphate of nickel, which gave the characteristic reactions for nickel and sulphuric acid, and also those for cobalt and iron. There was an insoluble brown residue of ferric oxide from the melt.

The mineral, therefore, was a *sulphide of nickel.*

Copper Pyrites.

$CuFeS_2$.

Gave the same reactions as those obtained in the case of chalcocite, *with the addition* of a copious reddish brown insoluble residue from the melt of

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ferric oxide. The solution of the melt in water was *blue*. The melt in the crucible was reddish-brown.

The mineral was therefore a *sulphide of copper and iron*.

Bournonite.

$Cu\ Pb\ SbS_3$

Melt after fusion *yellowish-green*. Treated with water gave a solution of *copper sulphate*, in which both copper and sulphuric acid were detected as in chalcocite, &c. The insoluble residue (after dissolving out all the copper sulphate) was found to be sulphate of lead and antimonious and antimonic oxides. A portion of this insoluble residue was treated with acid sulphate of potassium (as in stibnite), when all the antimony was eliminated as *antimoniuretted hydrogen*, and the residue of lead sulphate treated as the sulphate of lead obtained from galena, and the presence of lead demonstrated.

The mineral therefore was a *copper-lead sulph-antimonite*.

Tetrahedrite, or Fahl-ore.

$Cu_3\ Sb_2\ S_7$.

The melt was *green whilst fusing*, but *brown* when cold. Treated with water gave a *blue* solution of copper sulphate, ferric sulphate, and traces of zinc sulphate and arsenious acid. The usual tests were applied to this solution, and copper, iron, and sulphuric acid detected.

The residue insoluble in water was found to be antimonic oxide (Sb_2O_5) and ferric oxide. On boiling the residue with *caustic potash* the Sb_2O_5 was dissolved and the ferric oxide remained. On adding hydrochloric acid in excess to the antimonate of potassium and a piece of metallic zinc antimoniuretted hydrogen was detected in the way described above.

The mineral therefore was a *copper-iron,—&c. sulph-antimonite*.

Smaltite.

$(Co, Fe, Ni)\ As_2$.

The melt was *pink* whilst fusing. Treated with water and boiled, an insoluble residue of cobalt, iron and nickel oxides remained, whilst *arsenious acid* passed into solution, and the arsenic was detected in the usual manner. The oxides of the metals thus obtained were dissolved in hydrochloric acid and tested chemically for cobalt and nickel, also iron, and these metals were detected.

Where arsenic and antimony combine with metals forming antimonides and arsenides, *and no sulphur is present*, oxides of the metals are obtained together with oxides of antimony and arsenic. By adding sulphur to

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these compounds, *the metals are converted into sulphates and become soluble.*

I have still to discover a good method for the separation and detection of cobalt and nickel, suitable for mineralogical analysis.

In conclusion I must acknowledge the great assistance I have received from my assistant, Mr. Gilbert Rigg, in this investigation.

NOTE.—Since writing the above I have made some further experiments, and have succeeded in separating cobalt from nickel in the most complete manner. If the mineral is an arsenide or antimonide of cobalt and nickel it is fused as described in the treatment of smaltite, and when all the metals are converted into oxides a lump of ammonium nitrate is added to the melted mass from time to time, and the whole is kept gently simmering for three or four minutes. The melted mass assumes a pink colour due to the formation of nitrate of cobalt. After cooling the melt is boiled out with water; NiO remains behind absolutely free from CoO. The cobalt nitrate solution is evaporated to dryness in a porcelain basin and ignited at about 250°C, when all the ammonium nitrate present is volatilised and pure pink cobalt nitrate remains in the basin. If the mineral is a sulphide of nickel and cobalt fuse it with 10 per cent. of its weight of powdered carbon (previously added to the powdered mineral), and about four times its weight, or more, of caustic soda in a silver crucible. Sodium sulphide is produced, and dissolved out by water from the cooled melt, and the oxides of cobalt and nickel remain behind; they are then treated with ammonium nitrate as described above. C. A. B.

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A System for constructing Crystal Forms by the Plaiting of their Zones.

By J. Gorham, M.R.C.S.

(Abstract.)

[Read January 27th, 1891.]

In this paper the author described his method of constructing crystal models of paper or cardboard by means of plaiting. In the ordinary crystal "nets" (such as, according to Mr. Gorham, were constructed by himself and shown at the Royal Society as early as 1847) the faces of the model are drawn in juxtaposition on cardboard and cut out, some of the lines being only partially cut through; the net is then folded up so as to form a solid figure, and the faces are united at their edges by gum.

In the models described and exhibited by Mr. Gorham, the faces are so drawn as to be disposed along strips; these strips are united to each other at one end, and can then be folded together by a process resembling plaiting, in which the strips pass alternately under and over each other. In this way models are made precisely like those constructed from the ordinary nets, but requiring no cement; models which can, moreover, be taken to pieces (unplaited) and laid flat, or re-constructed whenever desired.

Each strip contains the faces lying in one zone, and the number of strips employed by Mr. Gorham is either three or four; the cube, for instance, is formed by the plaiting together of three, and the dodecahedron by the plaiting together of four strips.

Their order of succession is the same for each model whatever its form. Thus the strips of square faces from which the cube is constructed are three in number, and if they be denoted by the numerals 1, 2, 3 respectively, the process of plaiting always pursues the following order:—

1 passes over 2
then 3 „ 1
then 2 „ 3 and so on.

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Any model consisting of three strips is plaited in the same order.

A peculiar (and a new) feature of the models exhibited at the meeting is that their faces are traversed by lines; one strip is marked by a single line, the second by a double, and the third by a triple line. These lines fulfil a twofold purpose: (1) by their direction they show the number and disposition of the zones in each crystal (and indicate the order in which the strips are to be plaited); and (2) the alternate appearance and disappearance of the lines, that is to say their appearance on alternate faces of the model, is strongly suggestive of their being intertwined like a plait, as is of course the fact. It is to this alone that the model is indebted for its solid form and its power of retaining the same.

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REVIEWS.

An Introduction to the Study of Petrology: The Igneous Rocks. By F. H. Hatch, Ph.D., F.G.S., of the Geological Survey of the United Kingdom, with forty-three illustrations. London: Swan, Sonnenschein and Co., 1891.

English students and teachers have long felt the want of a convenient text-book dealing with the characters of the common rock-forming minerals and the chief types of rocks; and this want has now been admirably supplied by the publication of Dr. Hatch's little manual. In its general plan and in some of its details the book recalls many of the excellent features of the *Einleitung in die Petrographie*, the publication of which was one of the last among the great services rendered to geological science by the late Dr. A. von Lasaulx. In describing the means by which the rock-forming minerals may be distinguished from one another, Dr. Hatch wisely considers the requirements of the beginner, and dwells chiefly on those peculiarities which can be recognised without special optical appliances; the diagnosis which he gives with each species, being at the same time terse and accurate, is admirably adapted to the wants of the student. For the special optical characters, which are less easy of determination in ordinary thin sections, the reader is referred to more elaborate treatises on the subject, like that of Rosenbusch.

In the vexed question of rock nomenclature the author, while following the most recent German authorities, does wisely in referring also to the names employed by French and other authors. We think that something more might have been done with respect to those terms which are employed by modern German writers with significations different from those which were originally given them by their authors.

Dr. Hatch very properly points out that "Syenite" and "Gabbro" are now employed in a sense totally different to that in which they were understood by the older geological writers: he might have done the same with Vogelsang's names "Granophyre," "Felsophyre," and "Vitrophyre," the old French names "Minette" and "Kersantite," and several of Gümbel's names, which have been re-defined by Rosenbusch. The policy of taking old names and changing their definition is at best a very

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doubtful one; but it unquestionably entails upon the writers of text-books the duty of making clear the exact nature of the change and the date at which it has been made. If this be not done, the student who consults any geological paper written before the date of the proposed change is liable to be betrayed into serious errors. The book is admirably printed, with clear and useful drawings, taken for the most part from Fouqué and Lévy's admirable work, and it may be recommended to all beginners in this interesting study. J. W. J.

Asbestos: Its Properties, Occurrence and Uses. By R. H. JONES. Crosby, Lockwood and Sons. London, 1890.

This volume is an extension of a pamphlet issued by the author some three years ago on the same subject, which is here expanded into a treatise on the nature, sources, production and uses of asbestos, with supplementary chapters on its substitutes, and on fibre-spinning.

The term asbestos is used to include all substances which are commercially understood by that name; and under varieties of asbestos the author gives brief descriptions of the fibrous amphiboles, pyroxenes and serpentines. We are glad to note that he is here careful to distinguish between the Canadian "asbestos," or Chrysotile, and the Italian asbestos proper, a distinction which was by no means made clear in the above-mentioned pamphlet. As regards the production, mode of occurrence, and commercial uses of these minerals, the author deserves considerable praise for the manner in which he has treated the subject. The book contains a large amount of useful and interesting information, not easily accessible elsewhere, and is adorned by some excellent plates.

It is written, no doubt, to satisfy the wants of the general reader, who does not look for much accurate scientific information, and is obviously intended to call special attention to the Canadian "asbestos," perhaps somewhat to the disparagement of its Italian rival.

In a scientific journal we may be pardoned if we direct attention to the defects of what professes to be the scientific part of the book.

In this section the unscientific reader must be on his guard lest he accept the following as a history of the production of chrysotile:—"When first formed the serpentine is probably in a soft or pasty state, and contracts as it hardens (as if from drying), and in thus contracting breaks into thin, irregular, usually nearly parallel plates, incurving; and in the intervals between these plates the serpentine crystallises in the fibrous form we call chrysotile;" neither are "precious stones" generally sup-

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posed to be "volatilised in the clefts of the igneous rocks, and there turned into brilliant crystallisations."

Why, again, should the elevation of Griqualand West above the sea level lead to the expectation that asbestos will be found there?

Cat's-eye is described as a chalcedonic quartz; the tensile strength of crocidolite is attributed to the large amount of iron in its composition; and "pikrite" is described as a "bitter fibrous variety of serpentine."

The book, in spite of such blemishes, contains a really interesting account of the Canadian mines.

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Abstracts.

Formation of Minerals in Slags and Lavas compared. In the *Archiv for Mathematik og Naturvidenskab, Christiania* (1889) J. H. L. Vogt is giving an exhaustive *résumé* of what is known on this subject, with a large amount of new material, the object being to inquire (1) what chemical and physical conditions govern the formation of artificial minerals from a molten silicate-magma without water, steam, or *agents minéralisateurs* such as HF, and (2) how far these conditions are realised in the 'younger' volcanic rocks.

The magmas dealt with are such as contain (besides SiO_2) Al_2O_3, Fe_2O_3, FeO, MgO, CaO, MnO, Na_2O, and K_2O; not TiO_2, SnO_2, ZrO_2, WO_3, P_2O_5, B_2O_3, SO_3, CO_2, &c., nor the rarer bases PbO, ZnO, Li_2O, &c. The minerals known to be formed artificially from dry fusion are the olivine-group; the rhombic pyroxenes; the monoclinic and triclinic pyroxenes (augite, wollastonite, rhodonite, babingtonite); the lime and lime-soda felspars, albite (doubtful), but not the potash and potash-soda felspars; melilite and gehlenite; nepheline; leucite; magnesia-mica; garnet; and tridymite. There are also certain minerals not yet known in nature, such as the hexagonal and tetragonal lime-silicates, and others isomorphous with natural minerals, *e.g.* the lead-anorthite of Fouqué and Michel Lévy, in which PbO replaces CaO: finally the non-siliceous minerals,—spinels, magnetite, and hæmatite. Cordierite and idocrase are doubtful, as are meionite and other members of the scapolite series. Minerals not yet formed from dry fusion are quartz, orthoclase, microcline, anorthoclase, albite (?), the amphibole group, potash-mica, tourmaline, the pure alumina-silicates (andalusite, disthene, and sillimanite), topaz, staurolite, &c.: also, according to the author, the scapolite series, idocrase, cordierite, and the epidote group. Several of these minerals, however, do not occur in the younger lavas.

Under the olivine group we have forsterite, fayalite, and common olivine (with Mg and Fe), tephroite and the Mn-bearing olivines, monticellite and the lime-bearing olivines. These, except the last, are readily formed from slags, appearing as the earliest minerals to crystallise out. Monticellite is found in nature only in crystalline limestones, and the olivine of lavas

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contains little or no lime, though this base enters more readily into the composition of artificial olivines. The author examines the effect of the percentage of lime on the angles of the crystals.

With respect to the augites, the question arises whether the non-aluminous augites (diopside and hedenbergite series) have the exact formula $CaRSi_2O_6$, where R = Mg, Fe, Mn, or whether the ratio Ca : R may vary. It appears that the composition of artificial augites varies from $3CaSiO_3$, $MgSiO_3$ to $CaSiO_3$, $3MgSiO_3$. Excess of lime above the former limit appears as the hexagonal $CaSiO_3$; excess of magnesia above the latter limit as a rhombic pyroxene. With regard to the aluminous augites, it is inquired whether they can always be represented by the formula $RSiO_3 + nAl_2O_3$ or $RRSi_2O_6 + nRAl_2SiO_6$, or whether the alumina ever enters in some other combination. Microscopical examination shows that augite slags which are more acid than a bisilicate, *i.e.* contain more silica than the formula $RSiO_3 + n(AlFe)_2Si_3O_9$, always have more or less glassy residue. Those slags, however, which have a composition very near that of a bisilicate (two especially are cited with oxygen-ratios 2·00 and 1·97 respectively), crystallise completely as augite with no glass. The bulk-analysis of such a slag is therefore also that of the augite. Since the atomic-ratio Si : R in these is found to be not 1, but 1·23 and 1·25, the formula cannot be $RSiO_3 + nAl_2O_3$, and calculation shows that it is $RSiO_3 + nAl_2Si_3O_9$. It further appears that augite must form from magmas having approximately the composition $RSiO_3 + nAl_2Si_3O_9$, while we must expect quite different minerals (olivine, melilite and gehlenite, magnesia-mica, plagioclase) from magmas of composition $RSiO_3 + nAl_2O_3$. In natural augites the Al_2O_3 and Fe_2O_3 seem almost always to enter according to the formula $RSiO_3 + n(AlFe)_2O_3$ or $RRSi_2O_6 + nR(AlFe)_2SiO_6$; the combination $(AlFe)_2Si_3O_9$ occurs only exceptionally, but cases of it are quoted, besides the analogous occurrence of $Fe_2Si_3O_9$ in acmite and babingtonite.

The lime-silicate formed from dry fusion of magmas mainly consisting of $CaSiO_3$ is only very exceptionally wollastonite, in general a dimorphous substance in short hexagonal prisms, supposed to be truly hexagonal, but with optical anomalies. It may take up a small amount of $MgSiO_3$, but if the ratio Mg : Ca in the magma exceeds 1 : 4 an augite is formed instead. Alumina does not appear to enter into the constitution of this hexagonal mineral.

Enstatite and a dimorphous form of $MgSiO_3$ may be formed side by side from artificial magmas. Two slags having 5·5 and 3·5 times as much Mg as Ca, gave rise to the formation of both enstatite and augite, the latter often grown round a kernel of the former. The enstatite contains

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very little Ca, and the lime being thus concentrated in the 'mother-liquor,' augite is formed instead, after a certain point. The same slags also exhibit the new $MgSiO_3$, which belongs to one of the oblique systems. Fouqué and Michel-Lévy regarded it as monoclinic, and called it a MgO-pyroxene; but its cleavage and twin-lamellation differentiate it from the augites, and it may be triclinic. In like manner hypersthene ($FeSiO_3$) is found to have in artificial slags a dimorphous companion, mono- or triclinic with twin-lamellation and a basal cleavage distinguishing it from the augites.

Rhodonite forms very readily in Mn-bearing silicate-slags. The artificial crystals have almost always the combinations and habit of type 5 of Flink's series from Pajsberg and Längban, the shape being markedly tabular.

The memoir is not yet completed. A. H.

The Minerals of the Garnet Group (W. C. Brögger and H. Bäckström). (*Zeitschr. f. Krystallographie*, XVIII. pp. 209-276).

In this important paper the authors include under the garnet group all the orthosilicates belonging to the cubic system; the group is separated into two divisions, the first including those members which are of tetrahedral habit and cleavage, the second those whose habit and cleavage are dodecahedral. The first division comprises eulytine, zunyite, danalite, and helvine; the second division comprises garnet, sodalite, nosean, hauyne, lapis lazuli. Of these the last four are regarded by the authors as alkali-garnets, whose constitution is explained as follows.

The formula of a lime-alumina-garnet being $Ca_3 Al_2 (SiO_4)_3$, that of sodalite is regarded as $Na_4 [AlCl] Al_2 (SiO_4)_3$, in which two atoms of Ca have been replaced by four of Na, and one of Ca by the divalent group Al Cl.

The composition of nosean and hauyne is expressed by the formula $Na_4 [Al (NaSO_4)] Al_2 (SiO_4)_3$ which is derived from that of garnet by replacing Ca_3 by Na_4, and Ca by the divalent group Na SO_4 Al.

It need scarcely be pointed out that the above formulæ are totally different from those generally received. For example, Clarke and Groth express the constitution of sodalite as $Na_5 Al_4 (SiO_4)_4 Cl$.

A formula practically identical with that here adopted has only previously been suggested by Safarik.

The larger part of the paper is devoted to an examination of the nature and composition of lapis-lazuli, which has hitherto been generally regarded as a variety of hauyne.

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The authors find by an elaborate study of the best available specimens of lapis-lazuli that the substance is a contact mineral produced at the margin of dolomitic limestone, and is, in fact, a lime-silicate hornfels in which the lime-alumina-garnet generally characteristic of such rocks is replaced by a blue constituent having the composition of an alkali-garnet.

The typical constitution of this blue colouring matter is expressed by the formula—

$$Na_4\ [Al\ (S_3Na)]\ Al_2\ (SiO_4)_3$$

Denoting this substance U S_3, and using the symbol U S_2 to represent a substance having the composition $Na_4\ [Al\ (S_2Na)]\ Al_2\ (SiO_4)_3$, in which the radicle $NaSO_4$ of hauyne is replaced by the radicle S_2Na; and similarly using U S_1 to denote a substance into which the radicle SNa enters in place of the same; the authors find that the colouring matter of artificial ultramarine is also the substance U S_3.

A criticism of the various analyses of ultramarine then shows that the discrepancies hitherto remarked in the results of different observers may be explained by assuming that this substance is an isomorphous mixture in varying proportions of the following five homœomorphous compounds:—

$$US_1,\ US_2,\ US_3,\ Na_8Al_6Si_6O_{24},\ Na_2Al_2Si_4O_{12}$$

It is impossible in a short abstract to do justice to a paper which is the result of elaborate research and contains so much that is new; for the detailed account of the numerous observations and experiments upon which the authors base their views reference must be made to the original memoir. H. A. M.

Pinakiolite and Trimerite, two new minerals from the Manganese mines of Sweden, are described by G. Flink. (*Zeitschr. für Kyrstallographie*, 1890, XVIII. 361.)

Pinakiolite, which is found in small plates at Längbanshyttan in Wärmland, and is named from *πινακιον, small table*, and *λιθος, stone*, is associated with dolomite and hausmannite, and occurs in bands of crystalline laminæ in the dolomite. With it are found tephroite, small scales of manganophyllite, berzeliite, &c.

The characters are as follows:—

Sp. gr. = 3·881; Hardness = 6; very brittle; melts with great difficulty to a black non-magnetic mass; with bisulphate of potash and fluor spar the mineral colours the flame intense green. Reactions for manganese strongly marked. Dissolves in hydrochloric acid with evolution of chlorine, while flocculent silica is formed in the solution.

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After deducting water and silica, regarded as impurities, from the quantitative analysis, and calculating to 100, a result is obtained corresponding to the formula (MgO). B_2O_3. MnO. Mn_2O_3.

The analysis was as follows:—

	Found.
B_2O_3	16·05
MgO	29·30
Mn_3O_4	50·63
Fe_3O_4	2·12
CaO	1·12
PbO	0·78
	100·00

Crystalline system, Rhombic, $a : b : c = 0{\cdot}88385 : 1 : 0{\cdot}58807$.

Cleavage fairly perfect, parallel to the plane of the tables, which is here taken as brachypinakoid; imperfect in the direction of an undetermined macrodome; colour pure black; lustre strongly metallic. Colour of the powder brownish grey, which on heating becomes black. Very thin slices are transparent, strongly pleochroic. The acute negative bisectrix is perpendicular to the plate, and the axial angle is probably about 60°, the plane of the optic axes being the basal plane. The above orientation is adopted to show the analogy with Ludwigite.

Trimerite from Harstigen in Wärmland is named from τριμερής, *tripartite*, and has the following characters:—

Sp. gr. = 3·474. Hardness, 6-7. Cleavage basal, distinct. Fracture conchoidal.

Before the blow-pipe thin splinters melt in the hottest part of the flame, and form a dark mass. Silica, iron and manganese are easily recognised by the blow-pipe reactions. The powdered mineral dissolves in hot hydrochloric acid with separation of flocculent silica. Analysis leads to the formula—

$$Mn_2\,SiO_4 + Be_2\,SiO_4$$
$$\text{or } (Mn\,Be)\,SiO_4.$$

as shown by the following result:—

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	Found.
SiO_2	89·77
BeO	17·08
MnO	26·86
FeO	3·87
CaO	12·44
MgO	0·61
	100·63

The crystals are apparently short hexagonal prisms terminated by the basal plane and two pyramids, and goniometrical measurements give angles corresponding to the hexagonal system. It is shown, however, by Prof. W. C. Brögger, who investigated the optical properties of the crystals, that they are really asymmetric, being made up of three asymmetric individuals having a prism angle of 120°; lustre vitreous; colour yellowish-red; transparent. C. J. W.

In a suggestive paper immediately succeeding that of Flink, Prof. W. C. Brögger (p. 377) discusses the morphotropic relation of Pinakiolite and Trimerite to allied minerals, and shows that although apparently so widely separated, they may be placed in a morphotropic series, including Ludwigite and Willemite, to which they are obviously related, and also several other minerals, which are not generally brought together.

This series consists of the silicates R_2SiO_4, and the aluminates, ferrates, manganates and borates represented by the formula RX_2O_4.

In the silicates R = Ca, Fe, Mg, Mn, Zn, Be, &c., or (H_2Cu).

In the aluminates, &c., R = Be, H_2, (Mg_2O).

X = Al, B, Fe, Mn.

The crystals of the whole series, though belonging to different systems, are always characterised by one zone, with angles of about 60°, and exhibit a hexagonal or pseudo-hexagonal habit.

To this series Brögger refers the following minerals:—

Rhombic: Chrysoberyl, Diaspore, Manganite, Göthite.
Ludwigite, Pinakiolite.
Olivine group.

Pseudohexagonal: Trimerite.

Hexagonal: Phenakite, Willemite, Dioptase.

All these minerals resemble each other in habit, symmetry and mode of twinning. H. A. M.

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Hamlinite, a new rhombohedral mineral from the Herderite locality at Stoneham, Maine, is described by W. E. Hidden and S. L. Penfield. (*American Journal of Science*, Vol. XXXIX., 1890, p. 511.)

The mineral occurs as minute rhombohedral crystals attached to herderite and margarodite, and is associated with the rare beryllium silicate, bertrandite. Only an extremely small portion of the mineral has been obtained, and it is hoped that those who may have specimens of herderite will examine them, so that more material for analysis may be found.

The crystalline system is hexagonal (rhombohedral). The crystals vary from one to two millimetres in diameter, and are quite flat from the predominance of the basal pinakoid. They exhibit also the rhombohedra, R, $-2R$; the length of the vertical axis $c = 1{\cdot}135$ was calculated from the rhombohedron R = 108°2′.

Cleavage parallel to the base; lustre on basal plane pearly, on the rhombohedral faces greasy; transparent and colourless to faint yellow; double refraction positive, not strong; hardness 4·5; sp. gr. 3·228.

Fuses at about 4 to a white porcelain-like mass, colouring the flame pale green (P_2O_5); in the closed tube gives abundant water and etches glass (F). "We have therefore undoubtedly a new species, a phosphate (probably of beryllium and aluminium) containing fluorine, and one which promises to be of unusual interest." C. J. W.

Lussatite, a new crystallised mineral variety of Silica, is described by M. Er. Mallard (*Bull. Soc. Fr. Min.*, XIII. pp. 63-66).

The new mineral occurs on quartz crystals and on large chalcedonic concretions at Lussat, near Pont du Château, Puy de Dôme; also at Tresztyan, in Hungary, and in some localities in Cornwall. It consists of fibrous or fibro-lamellar matter, the fibres lying at right angles to the surfaces of the quartz crystals. These fibres on analysis are found to be almost pure silica, a residue of 0·011 of a sulphate having been noted after the mineral had been treated with hydrofluoric and sulphuric acids. The fibres, although themselves practically pure crystallised silica, are mixed with more or less amorphous silica (opal). The substance parts with eight per cent. of water on calcination. The fibres of Lussatite show distinct double refraction, but it is less strong than that of quartz. The extinction is exactly or almost exactly parallel to the length of the fibres, and the optical sign of the axis of elongation is positive. This serves to distinguish it from chalcedony, of which the optical sign is always negative. The double refraction of chalcedony is also stronger than that of Lussatite.

F. R.

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Minerals from Maryland (Johns Hopkins Univ. Circ. No. 75).—G. H. Williams adds a number of minerals to the list published two years ago for the Baltimore district. The highly micaceous gneiss of that region contains, in addition to garnet, kyanite and fibrolite, large black crystals of staurolite, frequently twinned. The crystalline limestone contains, among other minerals, orthoclase (necronite or 'fetid felspar') a green muscovite, not chromiferous, and pink scapolite in imperfect crystals up to 4 cm. in length. The eruptive granite contains allanite (orthite) surrounded by a parallel growth of epidote.

A. C. Gill describes chrome-tourmaline and chrome-muscovite (fuchsite), associated with chromite in the serpentine masses of Montgomery County. The former mineral occurs in dark green needles up to 2 cm. in length. It shows strong dichroism, the ordinary ray being chrome-green, the extraordinary greenish straw-colour. Specific gravity 3·089 to 3·062. The analysis (I.) is by T. M. Chatard. Compared with Cossa and Arzruni's analysis (II.) of the Ural chrome-tourmaline, it shows less chrome-oxide and more magnesia. The chrome-bearing mica (fuchsite) is of a beautiful green colour. Its pleochroism is α = delicate robin's-egg blue, β = yellowish-green, γ = rich bluish chrome-green; and the axial angle is 71°24′ for Li, and 68°16′ for Na. Side by side with T. M. Chatard's analysis (III.) of this mineral is given the analysis (IV.) by Damour of fuchsite from the Urals. It will be seen that in both the minerals the American specimens contain less Cr than those from the Urals.

		I.	II.	III.	IV.
SiO_2	...	36·56	36·79	42·21	46·17
TiO_2	...	0·09	—	—	—
P_2O_5	...	0·04	—	—	—
Fl	...	0·06	0·65	—	—
B_2O_3	...	8·90	9·51	—	—
Al_2O_3	...	32·58	30·56	34·55	29·71
Cr_2O_3	...	4·32	10·86	2·03	3·51
Fe_2O_3	...	0·79	(FeO 2·91)	1·03	2·03
NiO	...	0·05	—	—	—
MnO	...	strong trace	—	—	—
MgO	...	9·47	4·47	3·13	2·28
CaO	...	0·75	0·72	0·47	—
Na_2O	...	2·22	1·36	0·82	—
K_2O	...	0·13	—	9·16	10·40

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		I.	II.	III.	IV.
Li_2O	...	strong trace	—	—	—
H_2O	at 105°	0·07	2·25	6·77	5·42
	red heat	3·67			
		99·71			
O = Fl	...	0·02			
		99·69	100·08	100·17	99·52

A. H.

Gadolinite from Texas and Monazite from Canada (F. A. Genth in *Amer. Journ. Sci.* (3) Vol. XXXVIII. p. 198).

Gadolinite from Burnett and Llano counties, Texas. Black; thin splinters translucent with dark bottle-green colour; streak greenish-grey; fracture conchoidal to splintery; sp. gr. 4·201 and 4·254; analysis (Burnett Co.) given in Column I. below.

	I.		II.
SiO_2	22·87	SiO_2	0·91
Al_2O_3	0·28	ThO_2	12·60
Ce_2O_3 (ThO_2) ...	2·65	Ce_2O_3	24·80
$(Di, La)_2O_3$ ...	5·22	$(La, Di)_2O_3$ ...	26·41
$(Y, Er)_2O_3$ ...	44·35	$(Y, Er)_2O_3$ ...	4·76
BeO	9·24	Fe_2O_3	1·07
FeO	13·69		
MnO	0·22		
MgO	0·07	MgO	0·04
CaO	0·64	CaO	1·54
Na_2O	0·20	P_2O_5	26·86
K_2O	0·15		
Ignition ...	0·72	H_2O	0·78
	100·80		99·77

Monazite from Villeneuve Mica mine, Ottawa Co., Canada. Reddish brown; indistinct cleavage; little or slightly waxy lustre; sp. gr. 5·233; analysis given in Column II. A. H.

Sigterite, a new felspar.—C. Rammelsberg describes a new felspar which occurs in the form of grey granular particles associated with eudialyte and albite at Sigterö near Brevig. (*Neues Jahrb.*, 1890, Vol. p. 71). It has the optical properties of a felspar, with twin-lamellation

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On a flake parallel to the second cleavage the extinction-angle from the edge $P : M$ is + 16°; on a flake parallel to P the angle between the extinction-positions of adjacent lamellæ is 7° to 9°. Analyses give nearly the formula $Na_2Al_2Si_3O_{10}$; a much more basic constitution than that of the known alkali-felspars. It may be regarded as a combination of a normal and a semi-silicate; or (doubling the formula) as one molecule of albite combined with three of an alkali-anorthite. It also corresponds to natrolite deprived of its water, and the author suggests the possibility of the natrolite of the zircon-syenite being derived by hydration from Sigterite.

A. H.

Secondary Amphibole and Pyroxene Minerals.—Whitman Cross has recently described a novel mode of occurrence of certain amphiboles and pyroxenes near Silver Cliff in Custer County, Colorado. (*Amer. Journ. Sci.* (3) Vol. xxxix. p. 359; 1890.) The most interesting is a blue amphibole having the a—axis of elasticity inclined at only 13°—15° to the c—axis of crystallography, and giving the pleochroism-scheme: a = deep blue, β = purple to violet, γ = pale yellow; absorption $a > \beta > \gamma$. No complete analysis could be made, but the characters of the mineral bring it very near to riebeckite [see *Min. Mag.* Vol. viii. p. 167], and typical riebeckite with the characteristic intense absorption is found with it. The mineral occurs as an enlargement of original brown hornblende, or sometimes of pyroxene, and presents the usual crystallographic relation. In similar association occur a green or colourless actinolite and a dark-brown amphibole, perhaps barkevicite; and the author has no doubt of the secondary nature of these various amphibole minerals. As an alteration-product of the blue amphibole occur little prisms of a pleochroic pyroxene, giving a = green, β = clear green, γ = yellow, and referred to ægirine.

To bring out the relations which exist among the various members of the amphibole and pyroxene families, Cross adopts the treatment of the former family proposed by Tschermak and advocated (in the same number of the *Amer. Journ. Sci.*) by G. H. Williams; the plane usually named the orthodome $(\bar{1}01)$ is taken as basal plane (001). It then appears that in all the monoclinic amphiboles and pyroxenes the axes of greatest and least elasticity, a and γ, lie respectively in the acute and obtuse angles between the crystallographic axes a and c, and the angle between c and γ, reckoned always in the same direction, is as follows :—

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		°
Amphiboles :	Anthophyllite (rhombic)	0
	Glaucophane	5
	Tremolite, &c.	15
	Brown Hornblende	25
	Blue Amphibole of Silver Cliff ...	75
	Riebeckite	85
Pyroxenes :	Enstatite, &c. (rhombic)	0
	Spodumene	26
	Diopside, &c.	38
	Augite	45
	Augite	54
	Ægirine	87

Arfvedsonite will probably come near the blue amphibole as regards the orientation of its ellipsoid, but the discrimination between a and γ here appears to be open to doubt. Barkevicite, according to Rosenbusch's observations, will be near glaucophane. A. H.

The Pyroxenites of Maryland.—G. H. Williams, continuing his studies on the intrusive rocks of Maryland, divides the non-felspathic rocks into the peridotites and the pyroxenites (*American Geologist*, July 1890). The two groups are alike in being poor in alumina, but differ in their percentages of silica, which are typically 40 to 44, and 52 to 55 respectively. Further, in each group, the varying proportions of lime give rise to various members of the pyroxene families. In the former group olivine occurs in addition; in the latter pyroxenic minerals form the whole of the rock. For this group the name Pyroxenite is proposed to be reserved, the employment of this name by different authors in other senses being abandoned.

Of the Maryland pyroxenites one type consists of green diallage and red pleochroic hypersthene; the former slightly in excess, and being, if anything, slightly later in consolidation. An analysis of such a rock by J. E. Whitfield is given in column I.

	I.	II.	III.	IV.	V.
SiO_2	50·80	52·55	54·53	51·80	55·14
TiO_2	—	0·14	—	0·13	—
Al_2O_3	3·40	2·71	1·93	2·21	0·66
Cr_2O_3	0·32	0·44	0·30	0·51	0·25
Fe_2O_3	1·39	1·27	1·70	1·29	3·48

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	I.	II.	III.	IV.	V.
FeO	8·11	4·90	8·92	3·50	4·78
MnO	0·17	0·24	0·28	tr.	0·08
CaO	12·31	16·52	2·25	20·99	8·39
MgO	22·77	20·39	29·51	17·76	26·66
Na_2O	tr.	0·27	—	—	0·30
K_2O	tr.		—	—	—
H_2O	0·52	1·09	1·14	0·65	0·38
P_2O_5	—	tr.	—	tr.	0·23
Cl	0·24	—	—	—	—
	100·03	100·52	100·56	98·84	100·25
Sp. gr.	3·318	3·304	3·300	3·308	—

Another type is poorer in iron, and so lighter in weight and colour. It consists of reddish-brown bronzite and emerald-green diopside, the aggregate being usually even-grained, though a porphyritic development of the bronzite is sometimes observable. An analysis of one example, by T. M. Chatard, is given in column II. It contains about three parts of the rhombic pyroxene (III.) to one of the monoclinic (IV.). The figures show the former mineral to be a typical bronzite, while the latter agrees with the chrome-diopside of the lherzolites, &c. Another example of a bronzite-diopside rock comes from near Webster in North Carolina. This is rather more acid, and richer in magnesia, as is seen from the analysis (V.) by E. A. Schneider. Williams proposes the name Websterite for all the massive intrusives composed entirely of rhombic and monoclinic pyroxenes, and thus answering to Lherzolite among the peridotites. A. H.

Leucitophyres, &c., of the Laacher See District.—In a recent paper A. Martin gives a description of the leucitophyres and associated volcanic rocks in the district west of the Laacher See, with a useful summary of the extensive literature dealing with these rocks. (*Zeitschr. d. deutsch. geol. Ges.* XLII. p. 181, 1890.) The leucitophyres, which occur in a number of small outcrops, he divides into two groups: (i.) those without melanite, containing 53 or 54 *per cent.* of silica (Olbrück, Engelerkopf, Schillkpof, &c.), (ii.) melanite-bearing leucitophyres, with 48 or 49 *per cent.* of silica (Perlerkopf, Schorenberg, Rieden-Altenberg and the Hardt, Selberg). The former group have porphyritic crystals of nosean, more rarely sanidine, frequently leucite, &c., in a very fine-grained ground-mass of nepheline and

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sanidine with a smaller proportion of leucite and green augite. In the second group, which presents greater variety of characters, the porphyritic elements make up a larger part of the rock, and include nosean and leucite (the latter usually minute) with some sanidine, &c. In the rock of the Hardt the ground-mass consists mainly of small sanidines and nephelines; in that of Schorenberg of nepheline and augite, with but little sanidine; the Perlerkopf and Rieden-Altenberg rocks have but little proper ground-mass, large sanidine crystals enclosing the other constituents. Leucite always occurs, but not in great quantity. The alleged perofskite seems to be only melanite. The author finds that the so-called leucite-tuffs of the district belong to the leucitophyres, and that the eruptions lasted into the time of the Löss formation, being, at least in part, among the youngest products of vulcanicity in that region. [*Cf.* Busz's paper: abstract on p. 89 of this volume.]

The rock of the Selberg near Quiddelbach, some distance west of the above localities, is a phonolite containing olivine, though various writers have differed as to the presence of this mineral and also of the nepheline. It is a dark-grey rock with greasy lustre, and encloses large porphyritic hornblendes. The ground-mass consists of little sanidine crystals with fluxional arrangement and a smaller proportion of green augite. The abundance of hornblende and the presence of plagioclase among the porphyritic constituents bring this rock near to the tephrites, while the olivine, which occurs irregularly in nests, links it with the basanites.

The rock of the Hannebacher Ley, with respect to which Rosenbusch seems to have fallen into some confusion, consists of augite, nepheline, magnetite, melilite, and nosean, with only a little leucite, and perofskite. It contains no felspar and is to be referred to the nephelinites. The author further describes several basalts from different parts of the district, and he protests against the practice of distinguishing between "basalt" and "basalt-lava" according to the compact or scoriaceous character of the rock; a point of minor importance. A. H.

An Olivine-rock from Greenland.—The eighth part of the *Meddelelser om Grönland*, which has recently appeared, contains an account of an olivine-rock collected by J. A. D. Jensen at Siorarsuit on the west coast (lat. 65°44′ N), described and analysed by K. Rördam (pp. 125-180; 1889). Though less pure than the typical dunite of New Zealand, the rock consists mainly of olivine. It has a considerable extent, and its disintegrated substance forms a terrace 30 or 40 feet high, above which in some places rise solid masses of the hard rock, succeeded at an eleva-

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tion of 120 feet by the granite, which forms the bulk of the island. The rock has a yellow-green colour, with a hardness of 6·5, and a mean specific gravity 3·29. The powder is grey-green, with specific gravity 3·31. The accessory minerals are grammatite, magnesia-mica, and chromite.

		I.	II.	III.	IV.
SiO_2	...	39·17	43·81	40·01	42·80
Al_2O_3	...	3·80	3·29	0·06	—
FeO	...	10·56	10·31	16·21	9·40
MgO	...	43·46	38·13	43·09	47·38
NiO	...	trace	trace	0·54	—
CaO	...	faint trace	trace	—	—
K_2O	...	0·55	0·13	—	—
Na_2O	...			—	—
H_2O	...	0·91	1·41	—	0·57
Foreign matter		1·59	2·37	—	—
		99·54	99·45	99·91	100·15

I. Olivine-rock, Siorarsuit (K. Rördam).
II. Ditto partly serpentinised, ditto. (K. Rördam.)
III. Olivine, Ameralikfjord, Greenland (C. T. Lappe).
IV. Dunite, Dun Mt., N. Z. (Reuter).

Eliminating the accessory minerals, the Siorarsuit olivine is found to agree aproximately with the formula $7·5\ Mg_2SiO_4 + Fe_2SiO_4$. A. H.

Serpentines and Serpentinous Rocks from Hungary. (*Ueb. Serpentine u. serpentinähnliche Gesteine aus der Fruška-Gora; Jahrb. d. k. ungar. geol. Anst.*, Vol. VIII. 1889). In this district M. Kišpatic finds both true serpentines and serpentine-like rocks. The former are found to be derived from olivine-bearing rocks, the various stages of alteration being traceable in specimens from different localities. The original rocks were of four different types. One consisted almost entirely of olivine (olivine-rock); in the others a monoclinic and a rhombic pyroxene accompanied it, either separately (salite-peridotite and bronzite-peridotite) or both together (lherzolite). It is shown that the salite, as well as the bronzite, has given rise to the bastite-pseudomorphs embedded in the dark serpentine groundmass of most specimens. The 'serpentinähnlichen Gesteine' consist mainly of flakes of antigorite with a scaly and often a lattice-like structure. They are in great part derived from amphibolites, the gradual conversion

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of the amphibole into antigorite being plainly seen. In other specimens the latter mineral is seen to be formed from salite, of which grains often remain. A. H.

Crystalline Rocks of Bornholm. For the excursion of the German Geological Society to Bornholm, E. Cohen and W. Deecke have written an account of the crystalline rocks of that island (*Ueber das krystalline Grundgebirge der Insel Bornholm*, Greifswald, 1889). The dominant rock is described as amphibole-biotite-granite, and consists of white, red, or green felspars (microcline predominating), grey or colourless quartz, and abundant (microscopic) sphene. The basic constituents, which are not plentiful, are biotite and green hornblende: the latter has strong absorption parallel to β and γ, and gives an extinction-angle of 20° to 39°. There is also an amphibole-granite with biotite, in which the basic elements are more abundant, and this contains little or no sphene.

Besides veins of pegmatite, not sharply divided from the granite, there are numerous dykes of plagioclase-augite rocks. One type is an ophitic diabase, poor in olivine and with plentiful opaque iron-ores. The augite in this is sometimes pleochroic (β = reddish-yellow to light yellow, α and γ = greenish-grey to greyish-violet). Biotite is a constant accessory, and brown hornblende occurs in subordinate quantity: apatite-prisms are abundant. Another type is a non-ophitic olivine-diabase. The idiomorphic augite is light brown to violet-brown, rarely pleochroic; and the olivine forms large well-bounded crystals. Besides these types are olivine-diabases showing a gabbro-like habit, and others with a porphyritic structure, described as 'olivine-diabase-porphyrites.' A. H.

Variations in Dyke-rocks. A. C. Lawson and F. T. Shutt have pointed out some interesting differences between the marginal and central portions of diabase dykes in the Rainy Lake region, near Lake Superior. These variations are (i.) structural—the passage from a very fine-textured diabase-porphyrite at the contact-walls, through ophitic diabase, to a granular gabbro-type in the middle; (ii.) mineralogical—from a quartzless rock at the contact to a quartzose one in the middle of the dyke; (iii.) chemical—from a more basic rock near the contact to a more acid near the middle. The textural and structural variation is ascribed to different rates of cooling under constant pressure, the chemical differences to selective crystallisation of the more basic minerals in the earlier stages of solidification, with a transference of the acid residue from the sides to the middle by the agency of included water. (*Amer. Assoc. Proc.*, Vol. XXXVIII.)

A. H.

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A Picrite from Maine.—G. P. Merrill describes a peridotite which forms a uniform mass of compact greenish-black aspect on Little Deer Island, Penobscot Bay, Maine (*Proc. U. S. National Museum*, 1888, p. 191). Olivine, completely serpentinised, makes up two-thirds of the mass in the usual rounded grains embedded in plates of augite. The other constituents are magnetite and chromite, plagioclase (now scarcely visible), apatite, sillimanite (?), and pyrite, with possibly some unindividualised base. These characters and the analysis, by L. H. Merrill, place the rock among the picrites. Sp. gr. = 2·88.

SiO_2	38·01
Al_2O_3	5·32
Fe_2O_3	6·70
FeO	4·92
MgO	23·29
CaO	4·11
Na_2O	4·15
K_2O	0·22
Ignition	10·60

The most interesting feature of the rock is the enlargement of the augite plates by a secondary growth of paler augite substance in crystalline continuity with the original plates. This new-formed augite extends as a ragged fringe into the serpentine pseudomorphs, or even forms delicate branches following fissures in the now serpentinised olivine-grains. This seems to be the first record of such a feature in augite, though the 'secondary enlargement' of hornblende, and of augite by hornblende, is well known. A. H.

Variolite of Homertshausen, Hesse.—R. Brauns describes an interesting case of 'diabase-glass' and variolite occurring as a marginal facies where two lava streams of diabase have come in contact with one another (*Zeitschr. d. deutsch. geol. Gesell.* Vol. XLI. p. 502; 1889). The associated slates belong to the boundary between Upper Devonian and Culm. The extreme margin of the diabase sheet consists of a zone not more than 6 mm. thick, of dark green, almost black, glass. The specific gravity varies from 2·425 to 2·585, and the composition is that given under Column I. Column II. shows the analysis calculated up to 100 without the water.

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		I.	II.	III.
SiO_2	...	44·835	48·043	49·40
Al_2O_3	...	13·47	14·434	13·80
Fe_2O_3	...	11·79	12·633	—
FeO	...	4·49	4·811	18·17
MgO	...	11·605	12·435	10·67
CaO	...	4·795	5·137	—
Na_2O	...	2·34	2·507	—
H_2O	...	6·16	—	4·38
P_2O_5	...	trace	—	2·68
		99·485	100·000	99·10

For comparison, Column III. gives an analysis by Nordenskjöld of the Sordawalite from Finland; sp. gr. 2·58.

The zone next to the glass is somewhat variable. Sometimes it consists of a similar dark glass enclosing little white spherules, and this is followed by a zone 1½ cm. thick, of specific gravity 3·2, and of very compact appearance, with little crystals of olivine. In other places the little spherules in the glass become larger when traced inwards, the glass disappears, and is replaced by a yellow-brown paste, in which lie very numerous spherules as large as peas, giving a typical variolite. The variolite zone may be 10 cm. thick, more or less, and is often quite wanting.

From this zone inwards the rock developes into a fine-grained diabase, the outer part of which, for the thickness of 1 m. or more, is very compact. The diabase contains included fragments of limestone converted at the margin into coarsely granular marble.

The microscopic structure of the various types is fully described, and shows an interesting correspondence with the varieties of Sordawalite described by Löwinson-Lessing. [See *Min. Mag.* Vol. VIII. p. 164. The mode of occurrence is different from that of the Finland rock, which forms the margin of a dyke, but may be compared with the variolite of Mont Génèvre recently investigated by Messrs. Grenville Cole and Gregory.] A. H.

The Lamprophyres and Melaphyres of the Plauen Grund, near Dresden. By Bruno Doss. (*Tschermak's Min. u. Pet. Mittheilungen, XI. p. 17.*) In this paper, which is accompanied by a map and a plate of carefully executed microscopic drawings, the author gives an account of the mode of occurrence of certain veins or dykes cutting through the syenite which borders the left bank of the Weisseritz. Further north this syenite

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is overlaid by Upper Cretaceous and Quaternary deposits. The veins range from very trifling dimensions to dykes of 2 or 3 metres in breadth. They are referred by the author to Minette and Kersantite. They consist chiefly of biotite, orthoclase, greenish amphibole and chlorite. In addition to the orthoclase, microscopic examination shows that plagioclase and microperthite are present; also augite, pseudomorphs of hornblende, talc and serpentine, and pseudomorphs of quartz, &c. after olivine. Apatite, magnetite, titaniferous magnetite, sphene, rutile, zircon, spinel, hæmatite, limonite, epidote and carbonates also occur. Included fragments derived from the adjacent syenite are met with in these dykes. Schistose conditions of the lamphrophyres are also found, the schistose structure being considered by the author to be due either to parallel arrangement of mica-scales, sometimes at right angles, at others parallel to the sides of the dyke, or to mechanical stresses.

Some of these rocks are allied to augite-mica-syenite, and are occasionally rich in plagioclastic felspars; an analysis of one of them is given. The augite is mostly a colourless or pale-greenish malacolite. This, from dynamical action, sometimes passes into a fragmentary or crushed condition, at others it gives rise to a secondary development of biotite. Several modifications of hornblende occur in the minettes, including reedy, compact and acicular crystals, the latter being very minute and occurring either in felted aggregates within fissures in the rock, or as an alteration product in the pseudomorphs after olivine, which also occur in the minette. The hornblende has for the most part resulted from the alteration of augite, and this secondary development has frequently converted augite-minettes into hornblende-minettes.

The olivine-pseudomorphs are much more plentiful, and their boundaries are sharper near the contacts than in the central parts of the dykes, where they are sometimes represented only by rounded or amygdaloidal bodies. The olivine, once present in these rocks, is indeed only represented by pseudomorphs which consist of pilite, biotite, talc and magnetite, or finally of talc and magnetite. When this alteration is restricted to the outer border of the crystal, it is found, if the border consist of pilite, that the nuclear portion has been converted into chlorite. When the border consists of talc, then serpentine and carbonates have replaced the inner portion of the olivine crystal. Talc plays an important part in the replacement of the olivine. Nearly all the pseudomorphs after olivine have a coating of biotite. Among these pseudomorphs interpenetrating crossed twins are common, and, in places, are more plentiful than the simple crystals.

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The sphene which occurs in the minettes is in part primary, in part secondary. The felspar occurring in these rocks is mostly granular, but in the Kersantites it is chiefly in lath-shaped crystals. Microperthite is of rare occurrence in the minettes. The twin lamellation of the plagioclase is partly due to mechanical stresses. The biotite in these rocks passes into chlorite and the chlorite into talc. Where this alteration into chlorite has taken place rutile is of frequent occurrence, but it seldom appears under other circumstances. In the Kersantites the chloritic alteration is accompanied by the development of anatase.

Calcite and quartz occur in pseudomorphs replacing augite, the latter substitution being at times a direct one, at others it takes place indirectly from chlorite. The quartz occurring in the minettes also has a bordering of augite. In the Kersantites, on the other hand, it carries growths of secondary quartz, with an optical orientation similar to that of the invested grain or crystal. The secondary quartz contains magnetite dust and crystallites. The lamprophyre dykes are accompanied by scarcely any trace of exomorphous contact metamorphism. Endomorphous metamorphism is generally, but not always present. The granular structure of the dykes gradually becomes finer in texture towards their margins.

The melaphyre of the Plauen Grund consists, as a rule, of a very finely crystalline dark grey or blackish groundmass, in which beautifully developed augite crystals (2 to 3 mm. in diameter) occur. These may become less numerous, and scales of biotite (1 to 2 mm. in diameter) may take their place. In either case porphyritic pseudomorphs after olivine are present, with here and there a felspar crystal. The groundmass is a finely granular admixture of felspar and mica, in which are scattered minute crystals or grains of hornblende. Amygdaloidal structure occurs in different parts of the veins, but is often totally absent.

Concerning the veins occurring at the tunnel opposite Königsmühle, numerous opinions have been formed, and several pages are devoted to an account of the views of successive observers, dating from the year 1771 up to the present time.

From a microscopic examination of many specimens, the author describes the rock as consisting of well-developed crystals of augite, long, rod-like crystals of hornblende and crystals or grains of completely altered olivine, lying in a finely granular groundmass, composed of lath-shaped plagioclase and mica-scales with hornblende prisms, grains of augite, apatite needles and magnetite, together with various alteration products, all of which are described in detail. The augite and hornblende of the groundmass are capable of mutual replacement. The nuclear portions

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of the plagioclase crystals are very basic (anorthite), the borders are more acid (oligoclase).

The hornblendic mica-melaphyre is in no way connected with the lamprophyres of the Plauen Grund, and is distinguished from them by the presence of basaltic hornblende, of a basis, of an amygdaloidal structure, &c., but especially by the complete absence of any dynamo-metamorphic alteration. The mode of occurrence of the lamprophyres gives no further clue to their age than that they are younger than the syenite which they traverse and older than the overlying cretaceous deposits (Plänер). The illustrations given in the plate are chiefly of secondary growths and alterations, and of pseudomorphs after olivine, hornblende, &c. F. R.

Contributions to the Petrography of the Sandwich Islands. Edward S. Dana (*Am. J. Sci.* XXXVII., June 1889) describes the petrographical characters of a series of rocks from the Sandwich Islands, part of which were collected by Professor James D. Dana in 1887, and the remainder by the Rev. E. P. Baker, of Hilo, in 1888. The lavas of Mauna Loa fall into two main groups. The clinkstone-like basalts are in external aspect very like phonolites, and have specific gravities varying from 2·82 to 3·00. They contain little or no olivine. A characteristic feature is the beautiful radiating feather-like form assumed by the augite. The olivine basalts, on the other hand, are coarse grained and cellular with specific gravity ranging from 3·00 to 3·20. The olivine, which is abundant, occurs in very slender acicular crystals, elongated in the direction of the vertical axis.

The author gives a minute description of the delicate stalactites and stalagmites of Mauna Loa. They are found hanging from the roofs and rising from the floors of the long caverns left behind by the lava streams. Their peculiarity consists in the fact that the structure is coarsely crystalline throughout, so that it is not easy to say what could have been their mode of origin.

The lavas of Kilauea showed a general similarity to those of Mauna Loa. The more recent are dark coloured vesicular basalts containing little olivine. The augite occurs in the same feather-like forms as in many of the Mauna Loa lavas. Little or no glass was detected, even in specimens taken very near the glassy crust. The older lavas contain more olivine.

The lavas from the island of Maui differed widely from those of Mauna Loa and Kilauea. The most recent (from Haleakala) are dark coloured, scoriaceous and highly porphyritic with olivine and augite. The older

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lavas differ still more widely, approaching in structure and composition to augite-andesites, though the silica percentage conforms to that of normal basalt. A specimen from the west of Maui is described as a felspathic andesite. It contains some olivine and a little biotite, but the main mass is made up of penetration Carlsbad twins of oligoclase.

Some of the specimens from Maui and also from Oahu were much altered, more so than any of the Hawaiian lavas, G. T. P.

Formation of Cordierite in Vitrified Sandstones.—The curious vitrified sandstone fragments enclosed in some basalts of Central Germany have long been known, and the occurrence of numerous minute hexagonal crystals in the glassy matter between the quartz grains has been recorded. These are very abundant, especially in the paler parts (poorer in iron) of the glass. In 1875 Prohaska studied the glassy borders surrounding enclosed fragments of slate and quartzite in the basalt of Kollnitz in the Lavant Valley, and found there, besides spinel, microscopic cordierite, in crystals about 0·16 mm. long by 0·07 to 0·12 mm. broad (*Sitz. Wien. Akad., math. naturw. Classe*, Vol. XCII., p. 26). Here the interior of the fragments was free from cordierite, which must evidently belong to the zone of fusion and intermixture only. F. Zirkel finds, however, that the still smaller crystals known in the 'vitrified sandstones' are also cordierite. The crystals are compound twins, having the form of a pseudo-hexagonal prism contained by the faces (110) and (010), terminated by (001). There are no pyramid forms, but sometimes the edges of the prism zone are truncated by (100) and (130). Longitudinal sections are thus four-sided. They extinguish straight, and give pleochroism, vibrations parallel and perpendicular to the vertical axis ($c = a$) giving respectively pale yellow and bluish tints. The pleochroism is increased by heating for 6 or 8 minutes on platinum foil. The refringence and birefringence of the mineral are low (like quartz). There is no evident cleavage. Cross-sections have a hexagonal outline, and show the characteristic division into six optical fields. The best examples were obtained from the Steinberg, near Breuna, in the Habichtswald (*Neues Jahrb.* 1891, Vol. I. p. 109). A. H.

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Notes on Crystallites.

By Frank Rutley, F.G.S.
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[Read April 14th, 1891.]

THE work of the late Hermann Vogelsang, and the subsequent researches of O. Lehmann and other observers, have done much to show that a careful study of the rudimentary forms of crystallisation may prove as valuable to the mineralogist as that of embryology has already been to the comparative anatomist.

It is, indeed, difficult to form any clear conception of the manner in which a crystallite originated, nor can we go further back in the history of its development than a stage in which a number of atoms have been grouped in an arrangement about which there is yet no certainty, thus forming molecules grouped in some manner about which we are equally uncertain. We can but imagine that there is some inherent property in molecules which causes them, under given conditions, to group themselves in an orderly manner and to assume a form which may, when more fully developed, be referred to one of the recognised crystallographic systems.

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Vogelsang was the first to indicate that the globulite is the most rudimentary form, revealed as yet by the help of the microscope, from which crystalline bodies become developed.

The following extract, translated from Rosenbusch's *Mikroskopische Physiographie*,[1] may serve as an appropriate preface to the suggestions in this paper.

"Vogelsang, who lays stress upon the symmetrical polyhedral form as the principal means for acquiring an understanding of crystals, recognises the development of crystallites and that of crystals as two different methods of the process of crystallisation, which are united through gradual transition. Whether the one or the other event will take place in a solution is, according to his idea, dependent upon the relation between the molecular resisting-powers in the solution and the molecular movements within the globulites. The form of the globulite is, however, according to him, the chief condition which determines whether a crystallite or a crystal will result from it. Between the two an almost infinite number of growth-forms occur, interwoven-forms (*gestrickte Formen*), crystal-skeletons ('*Krystalskelette*'), often many-branched, in which the closed form of the true crystal is lacking, in which the globulite is no longer recognisable as such, and in which, when symmetrical relations permit it, double refraction is exhibited.

"In the theoretical discussion, with which Vogelsang accompanies his observations, he does not attempt any special explanation of the formation of the globulites, and he refers the movements and the arrangement of the developed globulites, as well as their transformation into integral parts of a true crystal, to a molecular movement (crystallisation-power) inherent in them, which enables them to attract one another and group themselves regularly."

The globulites, formed in Vogelsang's experiments with sulphur dissolved in bisulphide of carbon and Canada balsam, were supersaturated drops of the solution which, on parting with their solvent, became solid bodies, minute, transparent, isotropic pellets of sulphur.

It is customary to regard globulites as balls or spheres, but, when we consider how diminutive they are and how small they appear, even when magnified over 1,000 diameters, it seems quite probable that a globulite has not in all cases a perfectly spherical form, but may sometimes be an ellipsoid. The difference between a sphere and an ellipsoid of such small dimensions would barely be appreciable, even under very high magnifying

[1] 2nd Ed. Vol. I, p. 28.

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powers, and it does not, therefore, seem unreasonable to suppose that what we term globulites may include ellipsoids of rotation and triaxial ellipsoids as well as spheres.

Petrographical literature has already made us familiar with these minute bodies, individually known as globulites (Fig. 1), collectively as margarites (Fig. 2), longulites (Fig. 4), &c. In addition to these a vast number of other microscopic bodies have been described and figured, but up to the present time no distinctive names have been given to them. At the risk, therefore, of encumbering petrography with new terms I venture to suggest some of the names given in the annexed table. It would, indeed, be next to impossible for me to explain what follows without recourse to such terms. The names already in use are underlined.

This table may serve as a provisional but very crude classification of crystallites, in which four groups or stages are recognised. These may be regarded as shading off one into the other, as there are no sharp lines of demarcation between them.

I. PRIMITIVE STAGE.

Globulite.

Margarite. Clavalite. *Longulite.* Spiculite.

Bacillite. (*Belonite.*)

II. SPHERULITIC STAGE.

Cumulite.

Spherulite. *Globosphærite.*

Axiolite.

Scopulitic Spherulite. *Trichite.*

III. SETULATE STAGE.

Scopulite.

IV. CHIASMOLITIC STAGE.

Arculite. Furculite.

½ Arculite. Biconcave Rotulite.

¼ Arculite. Crenulite.

The first group or stage includes globulites, and those elongated forms which result from the coalescence, partial or complete, of several, sometimes of many globulites. These forms are too well known to need any description. The name clavalite is here given to club-ended longulites (Fig. 3), or dumb-bell shaped bodies, the term longulite being here restricted to cylindrical rods with rounded ends and of uniform dimensions from end to end of the cylinder. The bodies to which the name bacillite is given are of much greater size, and apparently consist of a number of longulites massed together with their longest axes parallel (Fig. 6). Th-

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term is convenient as indicating a rod-like body which does not present any recognisable crystallographic faces. The cumulite (Fig. 29) might be placed in this stage, but since these bodies appear at times to pass into globosphærites, they may be regarded as forming a connecting link between Stages I and II. They are here placed in the latter.

In Stage II. the cumulite (Fig. 29), or irregular aggregate of globulites, may, by accession of fresh globulites, ultimately form a spherical body known as a globosphærite (Fig. 30). Generally, however, spherulites have a radiating fibrous structure (Fig. 26), the fibres or minute crystalline rods diverging from a point or from several points situated at or about the centre of the spherulite. The rods may be either straight and single or they may split up into delicate branches. The surfaces of spherulites are sometimes smooth, at others rough, while occasionally their irregularity of surface is so great that their sections present roughly-jagged or toothed boundaries (Fig. 27), and in some cases, where the rock is almost wholly composed of them, they meet in polygonal boundaries. In these spherulites, with a radiating fibrous structure, we may assume that the separate fibres or rods have been formed by the linear arrangement of globulites, and in this respect they differ from those spherulites in which the globulites do not appear to have any definite arrangement, as in the globosphærites already mentioned. The elongated bodies known as axiolites possess the radial structure of a spherulite only to a limited extent, and that merely at the extremities of the axiolite (Fig. 25). Throughout the remainder of the body the fibres are radially disposed about a central axis, so that they lie at right angles to the roughly cylindrical surface of the axiolite. In general appearance they somewhat resemble spherulites which have been drawn or squeezed out of shape.

If we conceive the equatorial constriction of a plastic spherulite with a radiating fibrous structure, we can imagine that, according to the extent of the constriction, we should compress the fibres lying at right angles to the ligature and thus drive the remaining fibres into a sheaf-like form. By using a comparatively broad ligature we should form a rod, the length of which would be approximately proportional to the breadth of the ligature. The fibres passing from the ends of this rod would diverge around the poles of the compressed sphere and would sweep in curves towards the zone of constriction. This structure is not uncommon in some spherulites. Those shown in Figs. 23 and 24, occurring in a spherulitic lava from Mokua Weo Weo, in the Sandwich Islands, are good examples.

This kind of spherulite forms a connecting link between Stages II. and III. The trichites (Fig. 28), which have been provisionally placed in the

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same group with the spherulitic forms, may result either from the grouping of margarites about a common centre, or from the abnormal growth, as O. Lehmann has shown, of fresh material upon the terminations of crystals, so that they pass beyond the halo of crystallisation into the supersaturated mother liquor or magma, in which the currents bring such a plentiful supply of fresh material that the thin needle or thread increases very rapidly in length, while the impoverished solution streaming down its sides affords no material for increasing the breadth of the filament, the curvature of which he considers to be due to the action of currents.

Bearing the scopulitic-spherulite (Fig. 23) in mind, let us next turn our attention to the third or Setulate Stage, in which certain bodies occur which I have ventured to name scopulites in allusion to their brush-like character. In structure they appear to differ in no essential respect from the scopulitic spherulites, except that we can see little in them which suggests any relation to spherulites. This is, however, merely due to the length of the rod which carries the two brushes or plumes (Figs. 8 and 9), and if we wish to compare the very variable separation of the brushes, and consequently the variable lengths of the rods which carry them, we have only to examine a section of the well-known pitchstone of Corriegills, in Arran. Here we may see these scopulites in abundance; some with the brushes separated by long rods, others with the shortest possible stems. They frequently occur fringing the long spicular crystallites and spike-like rods of hornblende with their greenish tufts, and cause them to resemble the fronds of ferns, as in Fig. 10.[1] Scopulitic structure may also be seen in the hornblende of certain phonolites, hornblende schists, &c., the prisms splitting up at the ends into divergent fibres, as in Fig. 7.

Keeping this last or worn-out paint-brush type of scopulite before us, we pass on to the fourth or Chiasmolitic Stage. Here we have two forms of very common occurence in vitreous rocks, slags, &c., which I have termed arculites and furculites (Figs. 11 and 14) on account of structural peculiarities which respectively characterise them.[2] Of the two the arculite is the more closely allied to the scopulite. The leading characteristic of the arculite is the presence of four main ribs, like bows set back to back so that their concavities are facing outwards (Fig. 11). This structure may be

[1] This is a diagrammatic figure. These growths are frequently irregular. They sometimes occur as mere arborescent growths, as in Fig. 35, and are then barely recognisable as scopulites.

[2] Forms of this kind are described by Krukenberg as chiasmolites. "Mikrographia der Glasbasalte von Hawaii." Tübingen, 1877.

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seen in crystallites or crystal skeletons of felspar, olivine, &c., met with in certain volcanic rocks, usually vitreous. The structure, however, is not confined to crystallites, for distinct evidence of it may often be seen in well-formed crystals, as in the felspars of some trachytes, in which the skeleton structure, although its interstices are now filled in, is still clearly apparent. The four bow-like main ribs of the arculite are sometimes so close together that their convex sides are in actual contact, at others they are more or or less widely separated.

From their extremities towards the middle of each bow delicate comb-like growths are developed, those proceeding from the one bow following the direction of curvature of the adjacent bow. They are, as a rule, but slightly developed towards the middle of each bow. In section two bows or main ribs only appear, but in reality four are present in each fully-developed arculite.[1] Sometimes a small crystal form may be seen to occupy a position midway between the bows, and it not unfrequently happens that the bows are small or dwarfed, forming mere horns on the solid angles of the diminutive crystal form.

The arculites are very closely related to the furculites, which I have so named on account of their fork-like structure.[2] In the latter there appears to be a central main stem, which forks at its extremities into straight prongs which, as a rule, enclose tolerably wide angles (Fig. 14). At each extremity of the main stem there are four of these prongs. Two of them only are seen at each end of the main stem in microscopic section, when the plane of section is parallel to the main stem.

Pectinate growths proceed from each prong, those of the one prong apparently following the direction of the adjacent prong. The general structure so much resembles that of the arculite, that there is evidently a close relationship between these two forms.

In a furculite occurring in a section of Mexican obsidian there is a repeated tendency to develop scopulitic structure, the directions of the scopulitic fibres approximating to those of the pectinate growths of the furculite (Fig. 32).

The lath-shaped microlites so frequently seen in microscopic sections of volcanic rocks also seem, at times, to be in some respects related to furculites, especially those which, owing to an excessive growth from their solid angles, have developed projections of various kinds, sometimes

[1] In hemihedral forms, however, only two main ribs would be present.

[2] The forms which I have here termed arculites and furculites were named chiasmolites by Krukenberg, and I have in consequence applied the name to the group or stage in which they occur.

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swallow-tailed in form (Figs. 17 and 20), at others stepped or crenulated (Figs. 18 and 19). I have provisionally included them all in the preceding tabular classification under the name crenulites.

Allied to the furculites and arculites, but especially to the latter, are some peculiar forms which at first sight appear to belong to a separate group. It would seem, however, that they are hemihedral and tetartohedral forms derived from the arculite.

That shown in Fig. 18 appears to be derived from the arculite by the development of alternate pairs of octants, while that in Fig. 12 seems to result from the development of two octants (2 and 8, 1 and 7, 3 and 5, or 4 and 6), one above, and the opposite one below the diametral plane.[1]

The forms which we have now been considering comprise, I believe, the chief types upon which crystallites are built up. Doubtless there are others which I have never seen, or which may have been overlooked. There is, however, one peculiar form which I think is worth description.

This very remarkable example of discoidal crystallisation is afforded by the partial devitrification of a green glass from the St. Helen's Works, occurring in a large series of specimens forwarded to me by Mr. Douglas Herman for examination. This specimen, which is of a clear deep green colour, contains a great number of white, biconcave, circular discs, some of which occur singly (Fig. 15a), while others form interpenetrating groups, one disc lying at right angles to the other with the margin of the one passing through the centre of the other (Fig. 16). At other times they interpenetrate at an angle less than 90°, but as they are more or less deeply embedded in the glass, the angles at which they intersect cannot readily be measured. These bodies may clearly be seen by unassisted vision or by the help of a pocket-lens.

A large proportion of them appear massed together in a confused manner like heaps of diminutive coins. The concave surfaces of individuals occasionally meet or intersect, so that a small speck of green glass may be seen to occupy the centre of the disc. Where the specimen is broken and the fracture passes through one of these bodies, at right angles to its circular section, as in Fig. 15b, its biconcave nature is clearly revealed. For such a body I propose the name biconcave-rotulite.[2] Whether these rotulites bear any relation to spherulites has yet to

[1] The curved stems of these forms appear at times to consist of longulites, so grouped that they overlap like tiles on a roof (Fig. 31). See Explanation of Plate.

[2] When this paper was read the term biconcave-discolite was employed. Since, however, Prof. Judd objected to the term on the ground that it was already used to designate certain microscopic bodies occurring in calcareous deep-sea deposits, the name rotulite has been substituted.

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be determined, but in structure, at all events, they are quite different. In the biconcave-rotulite any section passing through its centre and at right angles to its circular section shows a structure which, in some cases, is precisely that of an arculite, in others that of a furculite. It would seem, indeed, that this form would result from the revolution of an arculite or of a furculite about an axis normal to the main stem.

We may assume that one section of the rotulite is circular, judging from the appearances which these bodies generally present in the hand-specimen. In a section cut from it, however, there are some rather small transparent sections which are decidedly hexagons, and on measuring the angle at which some of the more delicate crystalline growths, lying in the interior of the hexagon, intersect, it was found to be 60°. Such an hexagonal section may be derived from the interpenetration of three rotulites of equal dimensions at 60° to one another.

In the forms of the Chiasmolitic Stage which have just been described, the relation of the arculites, furculites, and rotulites appears to be a very close one. If now we compare the various forms of crenulites with those of arculites and furculites, we see in the boundaries of the former a certain approximation to the forms of the latter. Compare, for instance, Fig. 17 with Fig. 11, and Figs. 19, 20, and 21 with 14, and we can picture in the crenulites the partial or complete filling in of the skeleton-forms of arculites and furculites. In connexion with this it may be interesting to note that if a glass solid of the form which would result from the filling in of a furculite, such as that represented in Fig. 14, be devitrified, the lines in which the arrest-planes[1] meet would correspond in direction with the main stem and prongs of the furculite if the rate of the growth in the latter were equal in all directions, and a section through such a devitrified prism would resemble that shown in Fig. 34. In this instance, however, we have the lines, formed by the meeting of the divisional planes in the solid, resulting from the development of crystalline rods or bundles of crystalline rods, which, originating on the limiting surface of a polyhedral form, pass *inwards* until those proceeding from one surface arrest those proceeding from another surface, while in the filling in of a furculite we have growths which take place *outwards* from pre-existing lines. The one process is, in fact, the reverse of the other.

A few of the figures given in the plate have not yet been alluded to, but have been inserted as illustrative of certain structures already noticed. The figures are briefly described in the explanation of the plate.

[1] "Anniversary Address, Geological Society." By Prof. T. G. Bonney, 1885, *Proc. Royal Soc.* Vol. 39, p. 90. Herman and Rutley, 1885.

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In conclusion, the chief points suggested in this paper may be summarised as follows :—

Stage I.—The Primitive Stage comprises those bodies only which are either individual globulites, aggregates of globulites, forming elongated, moniliform, cylindrical or fusiform bodies, or bacillites resulting from the parallel grouping of such elongated forms. In no case has the globulitic element assumed a polyhedral form in this stage.

Stage II.—The Spherulitic Stage results from the grouping of members of the primitive stage into bodies which are usually more or less spherical, and sometimes with, at other times without, a radial arrangement. Occasionally these bodies show considerable departure from the spherical form, such differences being due to the same causes which determine the idiomorphic and allotriomorphic characters of crystals.

Stage III.—The Setulate is closely related to the preceding stage, the connecting link being the scopulitic spherulite. No pectinate growths are present in the scopulites, and they differ from one another only in the development and curvature of their constituent fibres, and in the length of rod by which their brushes are separated.

Stage IV.—The Sagittal Stage is related to the preceding, but less closely than at first sight appears. The fibres or rods of the scopulites do not bear any apparent relation to the curved main ribs of the arculites, or to the forked main ribs of the furculites, and consequently cannot be regarded as indicating definite arrest-planes. In the forms of the sagittal stage, which are essentially skeleton crystallites or crystals, there is a main skeleton which seems to correspond with the boundaries of the arrest-planes seen in similar glass solids when devitrified, these arrest-planes bearing a definite relation to the symmetry of the body in which they occur. Pectinate growths proceed from the limbs of the main skeletons of sagittal crystallites. No such growths are met with in the setulate stage.

By so shortening the central rod of the main skeleton of a furculite that the points from which the upper and lower series of forks originate are brought together, the central rod becomes abolished. If now the alternate forks of the upper series be brought together and also the alternate forks of the lower series, so that they coincide or unite to form a single rod, the skeleton will then become that of a pyramid or other closed simple form. Conversely, by separating the skeleton of a pyramid into forks, and by the development of a central rod separating the upper series of forks from the lower series, the skeleton of the corresponding prism is formed.

It seems probable, therefore, that the sagittal forms represent the frame

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work of all polyhedral crystallites or skeleton crystals. Much remains to be done in working out the relations of the forms.

How far the views expressed in the foregoing very imperfect sketch may be borne out by known facts or by further observations, is a question about which there is probably some doubt, and it may be that I have speculated far too freely and generalised to an unwarrantable extent upon the limited material at my disposal.

Explanation of Plate.

Typical Forms of Crystallites.

Primitive Stage.

1. Globulite. 2. Margarite. 3. Clavalite.
4. Longulite. 5. Spiculite. 6. Bacillite.

Setulate Stage.

7, 8, 9. Scopulites. 10. Scopulitic growths occurring in Pitchstone, Corriegills, Arran.

Chiasmolitic Stage.

11. Arculite. 12. $\frac{1}{4}$ Arculite. 13. $\frac{1}{2}$ Arculite. 14. Furculite. 15a. Biconcave-rotulite, St. Helen's Glass-works. 15b. Section of same, showing arculite structure. These bodies sometimes possess the structure of furculites.

16. Biconcave-rotulites interpenetrating apparently at right angles. St. Helen's Glass-works. 17, 18, 19, 20. Crenulites.

21. Same form as No. 20, but with the re-entering angles filled in.

22. Lath-shaped microlite.

Spherulitic Stage.

23. Scopulitic Spherulite.

24. Ditto, showing irregular boundary. Lava of Mokua Weo Weo, Sandwich Islands.

25. Axiolite, 26. Spherulite. 27. Spherulite with jagged boundary. Felsitic Lava, Glyder-Fawr, North Wales. 28. Trichite. 29. Cumulite. 30. Globosphærite.

Supplementary Illustrations.

31. Portion of slender undulate rod, the concave aspects of which show an imbricate arrangement of longulites. The orientation of the latter is the same on either side of the central or nodal point, but in the surrounding glass detached or barely adherent longulites may be seen; those on one side of the rod differing in their orientation from those on the other side. On focussing $\frac{1}{3500}$ inch lower, two other fringes of barely adherent longulites are brought into view, but they are orientated in directions the reverse of those seen at the higher focus. These fringes extend along the

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curved rod for about ⅓th of its entire length. Pitchstone, Corriegills, Arran. × 780 linear.

32. Portion of crystallite showing furculitic structure (F); passing into scopulitic structures (S). Obsidian, Mexico. × between 150 and 200 diameters.

33. Crystal of sanidine, twinned on Carlsbad type and showing divisional markings suggestive of furculitic structure. Trachyte, Berkum, near Bonn, Rhine. × cir. 80 diameters.

34. Diagrammatic vertical section of a square prism of glass, completely devitrified and showing the traces of arrest-planes joined by a central line of arrest which coincides with the principal axis of the prism. The resemblance of the divisional lines in this section to those observed in crystallites and crystals which show a furculitic structure is at once seen on comparing this figure with Figs. 32 and 33.

35. Irregular arborescent growths upon portion of a slender rod of hornblende in pitchstone, Corriegills, Arran. Examples are seen in this rock in which the direction of curvature of these growths upon one side of the rod is the reverse of that seen upon the opposite side. Such growths may be regarded as imperfectly developed scopulites, which, growing at close intervals and springing obliquely from their points of attachment, are unable to develop the perfect scopulitic form.

36, 37, 38, 39. Skeleton crystals in basalt-glass, Kilauea, Sandwich Islands. Three different sections, apparently of the same crystal form, are shown in Figs. 37, 38, and 39. Fig. 39 is probably a section approximately at right angles to the vertical axis.

40. Section similar to Fig. 39 (embryonic form). Basalt-glass, Kilauea. × 250 linear.

41. Skeleton crystal, Basalt-glass, Kilauea. × cir. 250 linear. Such a form might apparently be derived from that shown in Fig. 37 by shortening the central rod of the latter.

42. Skeleton crystal, basalt-glass, Kilauea. × cir. 250 linear, with small closed crystal-form developed in the centre.

43. Portion of crystal of sucrate of lime, showing arculite structure. The direction of maximum extinction makes an angle of 23° with the vertical axis.

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Devitrification of cracked and brecciated Obsidian.

By Grenville A. J. Cole, F.G.S.
(Professor of Geology in the Royal College of Science, Dublin.)

[Read April 14th, 1891.]

In examining a specimen of the rhyolitic lava-flow of the Rocche Rosse, Lipari,[1] in the collection of the Royal College of Science, London, I was struck by the fact that the areas of pure black glass visible upon the fractured surface were each bordered by a band of spherulitic matter, the convex surfaces of the spherulites being directed inwards towards the glassy area. The specimen, collected by Prof. J. W. Judd, F.R.S., evidently comes from a portion of the flow which has become brecciated during movement of the viscid mass; intermingling of glassy and hemicrystalline matter has occurred, and an approach to the structure of the well-known "Piperno" of Naples has resulted. But the irregular little lumps of obsidian have not received their spherulitic crust from any chilling effect that they may have had upon the surrounding groundmass; the spherulites belong to the glass-fragments themselves, and are not deposited upon their surfaces.

So much can be seen in the hand-specimen. Prof. Judd has kindly had a thin section prepared, which shows that this structure of glassy fragments with hemicrystalline envelopes is also a microscopic feature.

Thus the large lumps of obsidian exhibit a thin zone of spherulitic matter following every curve of their outline; the particular section examined has not traversed any examples of the thicker crusts so easily visible to the unaided eye. But the hemicrystalline interstitial matter, playing the part of groundmass in the specimen, unexpectedly exhibits the same characters on a minutely detailed scale. One or two lumps of dull normal rhyolite occur; but the main mass appears at the first sight to consist of well-developed axiolites, fitting closely against one another, irregular and curving, as in the fine examples from the Western States of America.

[1] See Prof. Judd, *Volcanoes*, p. 124.

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In axiolites, however, spherulitic aggregation has taken place along an axis; the body grows from this line outwards, and convexities of the surface occur where the normal spherulitic rather than the axiolitic tendency asserts itself. In the rock of the Rocche Rosse we soon see that the boundaries of the separate bodies are cracks, or even accidental lines of junction of adjacent fragments, and that the fibrous crystallisation has originated at the surface and spread gradually inwards, often leaving a glassy area at the centre. The minuter structure of the rock is thus merely a reproduction of that of its coarser portions.

The spherulitic envelopes, thus found to be so prevalent, are subsequent in origin to the fracturing and partial brecciation of the mass. A "eutaxitic" structure, like that of the Piperno or of the pitchstone of Spechtshausen in Saxony, having been set up in this layer of the lava-flow, sufficient heat remained in the mass to promote slow devitrification. The surfaces of the displaced fragments of obsidian, and the cracks which arose in the deformed and ruptured bands of glass, have served as starting-places for the crystalline tufts and spherules, which have only very rarely spread into the centre of the glassy particle. In this matter we have the strong support of the experiments of Messrs. Herman and Rutley[1] on the devitrification of artificial glass. The glass operated on, of whatever form, becomes opaque and crystalline from its surface inwards when exposed to prolonged heat short of the temperature of fusion. The fibrous groups of crystallites also develop along cracks;[2] and a purely microscopic fracture suffices for their production, as was shown by the experiment of flawing a piece of plate-glass beneath the scratch of a diamond, and subjecting the specimen to a bright red heat for nine days.[3] Hence, in the case of the lava of the Rocche Rosse, subsequent heating may have even fused the surfaces of adjacent fragments together; but the fact that a thin crack separated them before devitrification set in would account for the present disposition of the products of that process.

Mr. Rutley's experiments upon natural glassy rocks[4] confirm us in our opinion that spherulitic crusts will arise where fragments of obsidian, sufficiently consolidated for fracture, are subjected to renewed heating, or

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[1] "On the microscopic characters of some specimens of Devitrified Glass." *Proc. Roy. Soc.* Vol. XXXIX. pp. 87-107.

[2] *Ibid.* p. 99.

[3] *Ibid.* p. 107.

[4] "Notes on alteration induced by Heat in certain Vitreous Rocks." *Proc. Roy. Soc.* Vol. XL. p. 434.

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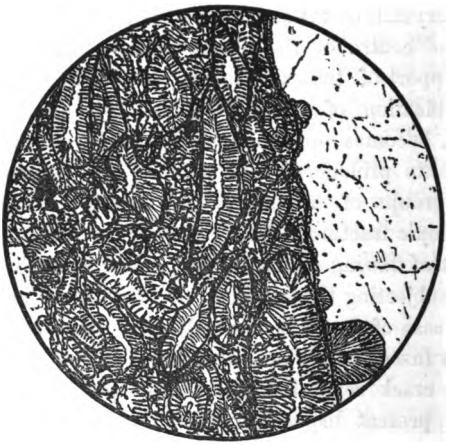
even to the slow passage of the residual heat from the lava-flow of which they form a part.

The structure above described merits consideration when cases of axiolites are under examination. On a microscopic scale it is possible to mistake the crack or line of junction between two obsidian fragments for the axis of an axiolite, and the two completely independent bands of spherulitic matter on opposite sides of it for a united axiolitic body.

Lastly, perlitic structure seems to arise in glassy lavas after the spherulitic stage has been passed through, or where it has been rendered impossible by the rapidity of cooling; but a perlitic glass subjected to renewed and sufficient heating ought to present very interesting and striking features of the Rocche Rosse type.

SECTION OF OBSIDIAN OF ROCCHE ROSSE, LIPARI.
× 18.



In the upper part of the field is a large glassy fragment, on the margin of which a thin spherulitic envelope has developed. The main part of the field is occupied by smaller fragments of glass, which have also become devitrified from their outer surfaces inwards.

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On the Occurrence of an Aluminous Serpentine (Pseudophyte) with flint-like appearance near Kynance Cove.

By Howard Fox, F.G.S.

[Communicated by Mr. Teall. Read April 14th, 1891.]

KYNANCE Cove lies in the midst of a Serpentine District. The Serpentine is associated with some little hornblende schist in the cove, and is traversed by black dykes both porphyritic and non-porphyritic from a few inches to several feet thick, by granitic veins, as also by veins of saussuritic gabbro, which latter, are, however, of rare occurrence on the western side of the Lizard.

When looking due east from the middle of Kynance Sands a rectangular block of white rock is seen in the dark red serpentine cliff from 70 to 80 ft. above the sea-level at low water, and about 200 yds. from the spectator. The vein that gives rise to this block can be easily reached by crossing the stream that enters the cove from the east, climbing the rising ground, and after reaching a ridge about 100 yds. from the stream, descending the grassy slope to the right to a point about 200 yds. south-east of Oliver's Refreshment House. Here, a few feet below the grass, a block of rock is seen 4 ft. high, 6 ft. through in front, and covered by broken serpentine behind. This block, which we will call No. 1, weathers in places an opaque white, like felspar, and in other places like broken flint. On fracturing it, some of the specimens obtained are found to be composed of a compact white substance, whilst others have the appearance of typical flint, from which they are easily distinguished by their softness. The opaque white rock is the hardest, and the flint-like rock the softest. This rock can be traced for 40 yds. running down the cliff in a south-south-east direction at an angle of about 18°. The serpentine has jointed out from the run of this vein, forming somewhat of a cleft, which renders the examination of the vein an easy matter. Twenty-five feet south-south-east of this block "No. 1" some more of the same rock is seen embedded in the light green soft decomposed serpentinous material which is so often associated with any disturbance in the serpentine of this district. The

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vein then becomes nipped out for a few feet, to reappear in the form of blocks of flint-like rock varying in size downwards from 2½ ft. long by 1 ft. thick, embedded in decomposed material as before. Sixty-four feet south-south-east of block "No. 1" we find the the large block "No. 2," which is so conspicuous an object from the sands. This block is 9 ft. long by 4 ft. thick, and lying behind it and connected with it is another block 2 ft. thick, which would indicate an original vein 6 ft. in thickness. The western face of this No. 2 block weathers like felspar, the rest weathers a dark colour. Some of the flint-like portions are translucent and of a greenish colour. These portions are much jointed, and in consequence of this the surfaces are roughened by angular projections. Some of the pieces broken from this block have the lighter and darker rocks in concentric layers, whilst others have alternate bands. A knife makes no impression on some of the opaque white rock, whilst some of the translucent rock yields to the nail. Fifteen feet beyond this "No. 2" block, the vein decreases to 1 ft. in width, and stones of flint-like rock are embedded in soft green material. Seven feet further on the vein forks and encloses a block of serpentine, the entire width of both veins and the included serpentine being about 2ft. Six feet further on the vein again branches, enclosing in its course masses of serpentine from 2½ to 3 ft. thick; the lower branch of the vein is from 4 to 6 ins. thick, showing much decomposed rock surrounding the flint-like rock; the upper branch is 6 to 9 ins. thick, and contains much flint-like rock in serpentinous material. The branches of the vein can be traced from this point to a small recess or cave into the back of which the upper vein is seen to disappear, having a dip of about 35° east-north-east. The end of this vein is about 120 ft. south-south-east of block No. 1.

About 20 ft. below this cave a vein of very coarse-grained saussuritic gabbro may be traced for several yards running parallel to the flint-like vein. This gabbro vein is 15 ins. thick in one place, and thins away to nothing. The edges of the saussurite in this vein become in some places beautifully translucent and of a light green colour, and bear a resemblance to the translucent angular projections of the flint-like rock of block "No. 2," described above. In fact there is a passage of the saussurite into the flint-like substance which forms the subject of this paper. The gabbro has, however, no connection with the flint-like vein. Ten feet south-west of this gabbro vein is a black dyke from 3 to 9 ins. thick running in a parallel direction. Further to the south, in the roof of a high cavern, an inaccessible oval block about 20 ft. long weathers in the same manner as the flint-like rock. Other black dykes occur here also.

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There is one other exposure of the flint-like rock. In ascending the rising ground after crossing the stream that enters Kynance Cove from the east (already referred to), we find, a little more than half-way up, say about 50 yds. above the stream, that the foot-path through the grass has laid bare some feet of this flint-like rock. One specimen is very soft, and is scratched by the nail. It is associated with and apparently passes into opaque white rock which is not scratched by the knife. This exposure is in the trend of the flint-like vein, and about 100 yds. north-north-east of block No. 1.

Mr. Player kindly analysed the flint-like rock for Mr. Teall, who has furnished me with the following result and analyses of some pseudophytes which supply an interesting comparison with that of this rock.

		Pseudophyte.		
	I.	II.	III.	IV.
SiO_2	33·3	33·51	34·63	35·81
Al_2O_3	21·8	15·42	17·13	18·28
Fe_2O_3	·4	—	—	1·26
FeO	—	2·58	1·61	·83
MgO	29·7	34·41	33·38	31·61
H_2O	14·9	13·21	13·93	13·26
	100·1	99·13	100·68	100·55
Sp. Gr.	2·57 2·54	2·61	2·58	2·61

I. Flint-like rock from Kynance.

II. Pseudophyte from Zdjar Mountain, near Aloysthal, Moravia,[1] (Hauer)

III. Greyish-green substance from Plaben, near Budweis.[2] (Drasche)

IV. Similar substance from Chyn, Bohemia.[3] (Gintl)

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[1] Dr. A. Kenngott, *Mineralogische Notizen Sitz. d. k. Akademie d. Wissenschaften. Wien.* Band XVII. (1855), p. 170.

[2] Dr. R. V. Drasche, Ueber eine pseudomorphe Bildung nach Feldspath. *Mineralogische Mittheilungen; Wien* 1873, p. 125.

[3] Quoted from Rammelsberg *Handbuch der Mineral-Chemie.* 2nd edit. Leipzig, 1875.

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The Optical Indicatrix and the Transmission of Light in Crystals.

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[Read June 16th, 1891.]

Section I.—Recent Change of View as to the Properties to be assigned to an elastic luminiferous Ether.

Deduction of the form of the wave-surface for biaxal crystals.

Fresnel's representation of the laws of transmission of rays of light in biaxal crystals, by reference to the surface distinguished by his name, has long been regarded as one of the greatest achievements in the domain of Physical Science. In his memoir[1] on Double Refraction, Fresnel proceeded as follows:—

1. He assumed that the transmission of a ray of light is effected by means of an elastic ether vibrating transversely to its direction.

To the ether is thus assigned a property not belonging to a perfectly fluid body in a state of rest: perfect fluidity of a body at rest involves incapacity of resistance to mere change of shape, and it is to such distortional resistance that transverse vibrations must be due.

2. He assumed that the ether of a crystal, when undisturbed, is a system of equal particles, in stable equilibrium under their mutual attractions; and that, for each pair of particles, the latter depend solely on some function of the distance between them and act in the line joining the centres.

He showed that in a medium so constituted there are at least three directions, at right angles to each other, such that the force necessary to the maintenance of a small displacement of a single particle of the ether along any one of them will act in the line of the displacement, and be proportional to it in magnitude: that the elastic force evoked by the displacement of a single particle of the ether through unit distance along each of these directions may be different, say a^2, b^2, c^2, respectively: that in this case, which is assumed to be that of the

[1] *Mémoires de l'Acad. de l'Institut de France*, 1827, vol. 7, pp. 45-176.

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ether in a biaxal crystal, the elastic force due to the displacement of a single particle of ether in any direction distinct from the three already mentioned will act in a direction different from that of the displacement; that if the direction of a radius vector of the surface $a^2x^2 + b^2y^2 + c^2z^2 = (x^2 + y^2 + z^2)^2$ represent that of the displacement of an ethereal particle, and the corresponding elastic force for a displacement through unit distance be resolved along and perpendicular to the line of displacement, the former component is proportional to the square of the radius vector in magnitude: that for displacements of a single particle in directions lying in a given plane passing through the centre of the above surface, the elastic force is generally obliquely inclined to the plane, but that there are always two directions, namely those of the longest and shortest diameters of the section of the above surface by the given plane, for which the resolved component of the elastic force in the given plane acts in the line of displacement.

3. He assumed that the ether is virtually incompressible for the forces concerned in the transmission of light.

Neglecting, therefore, the component of the elastic force normal to a plane containing a set of similarly displaced particles (wave-front) as being without effect by reason of the incompressibility of the ether, Fresnel inferred that, for particles in the given plane, vibrations parallel to either the longest or shortest diameter of the corresponding section of the above surface must be persistent, since the only effective component of the elastic force for each particle then acts in the direction of the displacement.

4. From a suggested but forced analogy of a line of vibrating ether-particles to a vibrating string, Fresnel assumed that the velocity of transference of a wave-front along its normal is directly proportional to the length of that principal diameter of the section of the above surface by the wave-front which is parallel to the direction of vibration.

Hence finding, by the usual mathematical process, the envelope of planes representing the positions to which wave-fronts, with every possible direction, would arrive after the lapse of the same interval of time, Fresnel concluded that the wave-surface for a biaxal crystal is represented by the equation

$$\frac{a^2x^2}{r^2-a^2} + \frac{b^2y^2}{r^2-b^2} + \frac{c^2z^2}{r^2-c^2} = 0:$$

further, as the front corresponding to any ray is parallel to the tangent plane to the wave-surface at the point where the ray meets it, the vibration is, in general, obliquely not perpendicularly transverse to the direction of the ray.

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5. Hence Fresnel also inferred that the velocities of the two rays which can be transmitted along a given direction are directly proportional to the axes of the ellipse in which the ellipsoid $\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2} = 1$ is intersected by a plane normal to the common direction of the rays.

Its singularities of form.

The closed surface represented by the above equation is of very peculiar form, and consists of two concentric ellipsoid-like sheets, which are symmetrical with respect to three rectangular planes. There are four points common to both sheets; they are situated at the extremities of two diameters lying in one of the planes of symmetry: in the neighbourhood of each of these points the sheets are drawn towards each other, and the surface has there the shape of a double cone; an infinite number of tangent planes to the surface can thus be drawn at each of them. Further, two planes and their parallels respectively touch the surface, not at one point nor at two points, but at an infinite number of points which lie on the circumference of a circle.

These geometrical singularities of the wave-surface, first noticed by Sir William Hamilton five years after the death of Fresnel, point to the existence in biaxal crystals of certain optical characters which had up to that time remained undiscovered, and seemed too strange to be real: the establishment of their actuality by Lloyd has been regarded as the crowning triumph of Fresnel's theory of double refraction; for not only are the phenomena strange, but their observation demands a combination of circumstances which places them beyond the range of accidental discovery.

Dynamical difficulties of Fresnel's theory of double refraction.

As continued experiment and precise observation have served only to establish the high degree of accuracy of the form assigned to the wave-surface by Fresnel,[1] it might naturally be inferred that the assumptions which lead, after so elaborate a course of reasoning, to a surface presenting these singularities must be themselves beyond cavil. Yet, strange to say, the mathematical process, by which the surface is thus arrived at, is one of which the weakness was recognised by the author himself, and the

[1] Kohlrausch: *Wied. Ann.*; 1879, vol. 6, p. 86; vol. 7, p. 427.
Glazebrook: *Phil. Trans.*; 1879, vol. 170, part 1, p. 287. *Proc. Roy. Soc.*; 1883, vol. 34, p. 393.

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theory has long been regarded as dynamically unsound; further, the characters assumed for the ether, though they lead to the true wave-surface, have since been found to have for necessary consequences other optical laws which are inconsistent with the results of experiment. On the other hand, the same form of wave-surface can be arrived at from other sets of assumptions, which have thus the same claim to recognition;[1] yet they are inconsistent with those of Fresnel, and with each other. As the later hypotheses which lead to Fresnel's wave-surface have been found to have other consequences which are contradicted by experimental results, the comparative simplicity and the historical interest of the method of Fresnel have sufficed to secure the adoption of his assumptions and corresponding terminology in the general literature relating to the optical characters of crystals.

The fact that Fresnel's wave-surface has been deduced from several inconsistent sets of assumptions as to the characters of the ethereal motion suggests that the form may really depend on the feature common to all, namely, the transmission of a periodic change of state differently related to different sides of the ray, and is otherwise independent of the physical character of the transmitted change: the suggestion is discussed in Section V.

Results of the rigorous calculation of the vibratory motion of an elastic solid.

The rigorous calculation[2] of the vibratory motion of the parts of an isotropic elastic solid is found to involve two quantities, which are generally denoted by A and B: the latter, B, measures the rigidity, or the resistance of the body to simple change of shape, or the *elasticity of figure;* the former, A, is connected with B, and with k (which measures the resistance to simple change of volume, or the *elasticity of volume*), by the relation $k=A-\frac{4}{3}B$. Further, it can be shown that a vibratory motion of the parts of an elastic medium generally gives rise to two kinds of waves, due respectively to distortional and condensational-rarefactional vibrations; the former travelling with velocity $\sqrt{\frac{B}{\rho}}$, the latter (which correspond to those of sound) with velocity $\sqrt{\frac{A}{\rho}}$, where ρ is the density of the medium. Now, if the transmission of light through a singly refractive medium be

[1] *e.g.* Challis in the *Trans. Camb. Phil. Soc.;* 1847, vol. 8, p. 524.

[2] A most Valuable Report by Glazebrook on Optical Theories is published in the *Rep. Brit. Assoc.* for 1885, pp. 157-261.

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due to the vibratory motion of an isotropic elastic solid, all the energy persists in the form of distortional vibrations perpendicular to the ray; hence the characters of the ether must be so assumed as to secure the absence of the condensational-rarefactional vibrations. For this purpose we may make either of two assumptions, namely, that A is virtually zero or that A is virtually infinite as compared with B: in the former case the condensational-rarefactional wave is got rid of by making its velocity zero; in the latter case by making the velocity infinite. But it was long believed that the former assumption was otherwise inadmissible: for it was supposed by Green and later mathematicians that the quantity $A-\frac{4}{3}B$ is necessarily positive, if the equilibrium of the parts of an elastic body is stable; and this is impossible if A is zero, for B is essentially a positive quantity: hence it only remained to assume A and therefore also k infinite, and thus the ether to be virtually incompressible.

Double refraction could then be consistently explained by a variation of the rigidity of the ether of a bi-refractive crystal with the direction; but it was necessary, for dynamical reasons, to assume the vibrations to be in, not perpendicular to, the plane of polarisation.

On the other hand, Lord Rayleigh[1] has proved that the phenomena due to the scattering of light by small particles require the vibrations of the ether to be perpendicular to the plane of polarisation; he has further shown that no theory based on varying rigidity can possibly be satisfactory, and that the variation of density in different directions in a biaxal crystal would lead dynamically to a form of wave-surface different from that of Fresnel, if the ether be incompressible for the forces involved in the propagation of the vibrations.

Sir William Thomson's version of the elastic theory.

From this position of dead-lock, according to which the ether must be both compressible and incompressible, the theory that the transmission of light is effected by the vibrations of an elastic medium has only recently been extricated. At the end of 1888 Sir William Thomson,[2] re-examining the problem of the stability of the equilibrium, found that the condition that $A-\frac{4}{3}B$ is a positive quantity becomes unnecessary, "provided we either suppose the medium to extend all through boundless space, or give it a fixed containing vessel as its boundary:" with either of these provisions, the stability only requires that A should not be negative, and it is therefore possible to get rid of the condensational-rarefactional wave by

[1] *Lond. Edin. and Dub. Philos. Magaz.*, 1871, ser. 4, vol. 41, p. 451.

[2] *Ibid.*, 1888, ser. 5, vol. 26, p. 414.

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the assumption hitherto deemed inadmissible, namely, that A is zero; this involves the compressibility of the ether for the forces concerned in the propagation of light. As a mechanical illustration, Sir William points out that "homogeneous air-less foam held from collapse by adhesion to a containing vessel, which may be infinitely distant all round, exactly fulfils the condition of zero-velocity for the condensational-rarefactional wave; while it has a definite rigidity and elasticity of form, and a definite velocity of distortional wave, which can easily be calculated with a fair approximation to absolute accuracy."

Starting with the new assumption, Sir William Thomson was able to deduce correct expressions for the intensities of ordinarily reflected or refracted light: and Glazebrook[1] has since shown that the elastic theory in its new form fully accounts for dispersion, including anomalous dispersion (like that of cyanin), double refraction, and metallic reflection, and further that it leads to a correct expression for the velocity of light in a moving medium. According to the new version, the vibrations of the ether are perpendicular to the plane of polarisation, even in biaxal crystals, and thus always perpendicularly transverse to the ray: further, the matter-particles and ether-particles are supposed to react on each other: and if their vibrations are synchronous, the former may even be set in appreciable motion by the latter. As the reaction of the matter and ether may produce the same effect on the motion of the ether-particles as would result from a simple variation of the rigidity or density of the ethereal medium, it becomes convenient to distinguish between the *actual* and *effective* values of the rigidity and density.

It is clear that the new version of the properties of the elastic ether, whether really true or not,[2] is far more satisfactory than any hitherto suggested, and must replace the older versions until a better one is proposed. Hence it becomes necessary, for those who adopt an elastic ether as the basis of the undulatory theory, to regard (1) the ether as compressible, even for the forces concerned in the propagation of light; (2) the actual density and rigidity of the ether as identical for all bodies; (3) the effective rigidity as invariable; (4) the effective density as different in different bodies, and, in the case of doubly refractive crystals, in different directions within the same body.

Fresnel's line of reasoning, and the terms based upon it, must be abandoned.

For the great majority of mineralogical students, the chief value of the

[1] *Ibid.*, 1888, ser. 5, vol. 26, p. 521.

[2] *Ibid.*, p. 538; 1889, vol. 27, pp. 246, 253: *Nature*, 1889, vol. 40, p. 32.

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hypothesis of an elastic ether is in the correlation of the phenomena observed when light is transmitted through crystals; for which purpose it is very desirable that the student should be able to reach the wave-surface, if practicable, by means of elementary reasoning based on observed facts of a simple character. The rigorous calculation of the motions of a vibrating elastic medium is not a simple process: it involves, indeed, mathematics of so high an order that the derivation of the wave-surface in this way will always be unintelligible to the ordinary student of crystals. On the other hand, the only comparatively simple mode of derivation of the wave-surface, as yet invented, that of Fresnel, depends upon assumptions of incompressibility and varying elasticity which are now deemed untrue; and further, involves for biaxal crystals a general obliquity of transverse vibration, not in accordance with the latest version of the elastic theory. Under present circumstances, the process of Fresnel, even if adopted on account of its great historical interest, must be puzzling to the student, and inevitably lead to the acquisition of wrong views as to the properties to be assigned to the luminiferous ether; hence it becomes necessary to abandon the whole process, and all those terms now in common use (ellipsoid of optic elasticity, axes of optic elasticity, coefficients of optic elasticity) which are based upon it.

The form of the wave-surface for biaxal crystals was really discovered in another way.

The great difficulty in the correlation of the phenomena of the transmission of light through biaxal crystals, as already stated, lies in the derivation of the wave-surface. The form of the surface is too extraordinary to be directly assumed either as a probable one *a priori*, or as suggested by experimental results. If it can be shown that the form of the wave-surface for biaxal crystals is suggested by a simple generalisation, independently of any particular version of the undulatory theory, and might have been brought in this way within the province of experimental investigation, the greater part of the present educational difficulty will be removed from the path of the student. In fact, we shall find that it was really by a process of generalisation, though not indicated in the composite memoir of 1827, that Fresnel himself was first led to the true form of the wave-surface for biaxal crystals. The properties of an incompressible elastic ether were mathematically developed by him after the discovery of the true form of the wave-surface had been made.

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Section II.—Evolution of the Optical Indicatrix.

In the present Section it is sought to show that a certain surface, here termed the Optical Indicatrix, naturally suggests itself as a means of correlation of the laws of transmission of light in uniaxal crystals; a simple generalisation then suggests the possible existence of biaxal crystals, and the general nature of their optical properties. The reasoning may be arranged as follows:—

General nature of light.

Light travels with finite velocity.

A flash of light transmitted from one body to another may thus for a time be wholly in the intervening space; hence the transmission of light must be one either of matter or of change of state of matter.

Light is due to the change of state of matter.

Two rays of light of the same colour, travelling in the same direction along the same line, may annihilate each other.

Hence the transmission of light cannot be one of matter; it must be a transmission of change of state of matter, and the change must be capable of representation by positive and negative quantities.

An ether is necessary.

Light travels across interplanetary space.

Hence interplanetary space must be filled with one or more kinds of matter, capable of transmitting a particular kind of change of state with an enormous but finite velocity (186,000 miles a second), and for distances amounting to millions of millions of miles. We may conveniently assume that the extraordinary matter is wholly of one kind, and designate it by a special name, *ether;* it must be extremely subtle, for it offers no appreciable resistance to the motion of the planets.

Permeation of ordinary matter by the ether.

Light is transmitted, but with different velocities, through ordinary matter.

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Hence either ordinary matter is itself capable of transmitting this particular kind of change of state, or it is permeated by an ether capable of so doing. Having regard to the enormous velocity with which light is propagated through interplanetary ether and different kinds of ordinary matter, we may assume that the same kind of ether is concerned in the transmission, and that the variation of velocity and other characters is due to the influence of the ordinary matter on the properties of the permeating ether.

The change of state is periodic.

If two rays, continually transmitted along the same line, annihilate each other, annihilation again takes place if either ray is transferred through any multiple of a certain measurable distance along the direction of transmission.

Hence, so long as a single ray of light is being transmitted along a line, the state of the ether at a given instant is the same at all points distant from each other by a certain measurable quantity, which we may denote by λ. But the continual uniform transmission of the change of state along the line involves a continual and periodic change of state at each point of the line; the duration of the period being the same at all points, and always equal to the time necessary for the transmission of the change through the distance λ along the line: if v be the distance of transmission during the unit of time, the period will thus be $\frac{\lambda}{v}$. During a single period, the ether at any point in the line of transmission experiences all those changes which belong at a given instant to all points in a length λ of the line of transmission.

The characters of an undulation.

Whatever be its physical nature, a periodic change of character at any point is termed a *vibration* of the character: its maximum value, the *amplitude* of the vibration: the interval of time required for a complete vibration, its *period:* the state at a given instant, the *phase* of the vibration: the relation between the phase and the time, the *law* of the vibration. If, further, the change is being transmitted along a line or *ray*, the configuration of the states at all points of the ray at a given instant is termed an *undulation:* the least part of an undulation which includes all varieties of phase is termed a *wave*, and the distance occupied by a wave, a *wave-length.*

Light is an undulatory phenomenon.

It follows from the above that, in this general sense, light is undoubtedly an undulatory phenomenon of some kind or other.

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Sound is also an undulatory phenomenon.

By similar reasoning, it follows that sound is an undulatory phenomenon. Experiment shows that the transmission of sound is effected by ordinary matter, and that the change of character is one of oscillation of the material particles, the oscillation being generally solely in the direction of the transmission. The properties at any point of a line of transmission of a continued uniform sound, namely intensity, note and *timbre*, must depend on the characters of the vibration at the point, and thus on the amplitude, period and law: experiment proves that the intensity of a simple sound depends solely on the amplitude, and the note solely on the period.

Intensity of light depends on the amplitude, colour on the period of the vibration.

Similarly, the corresponding properties at any point of a ray of ordinary light, intensity and colour, may be assumed to depend on the characters of the vibration at the point, and thus on the amplitude, period and law: we may tentatively assume, from analogy with sound, that the intensity of a simple ray depends solely on the amplitude, the colour solely on the period.

Polarisation of light: plane of polarisation: transverse plane.

But ordinary light is capable of a change to which there is no parallel in the case of sound. A ray of ordinary light transmitted through air acquires distinctive characters by reflection at a certain angle of incidence from a sheet of glass: as tested by reflection at the same angle of incidence from a second plate of glass, it has different properties on different sides; its properties being symmetrical, however, at every point of the path to the same two perpendicular planes intersecting in the ray: one of the planes of symmetry is the plane of incidence and reflection from the first plate. As the planes of symmetry of the ray are dissimilar and can be experimentally distinguished from each other, that which coincides with the plane of incidence and reflection may conveniently be termed the *plane of polarisation;* the second plane of symmetry may be distinguished as the *transverse plane.* A ray having the same characters, however induced, is said to be plane-polarised.

Hence the periodic change of the ether at any point of an aerially transmitted plane-polarised ray of light is not solely related to the direction of transmission, and thus differs in kind from that which characterises sound. For the suggestion of the laws of double refraction, preciser knowledge of the character of the change is unnecessary.

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Transmission of plane-polarised rays in glass and analogous media.

If a plate of ordinary glass or any analogous medium be placed with its faces perpendicular to an aerially transmitted plane-polarised ray, the light which emerges from the glass is found to be still plane-polarised, and the position of the plane of polarisation is found to be unaltered whatever the thickness of the plate: this is still true, if the plate be turned through any angle round its own normal.

As the direction of the ray within the plate is coincident with the direction of the ray before incidence and after emergence, we may thus reasonably assume that, at all points of the line of transmission *within the plate itself*, the periodic change of the ether is symmetrical to the same two planes; in which case the position of the symmetral planes of the periodic change is wholly independent of the glass and depends only on the direction of the plane of polarisation of the incident ray. A plane-polarised ray transmissible in any direction within such a medium may have any azimuth of plane of polarisation whatever.

Geometrical representation of the characters of a ray of plane-polarised light.

In representing the transmission of a ray of plane-polarised light, of a

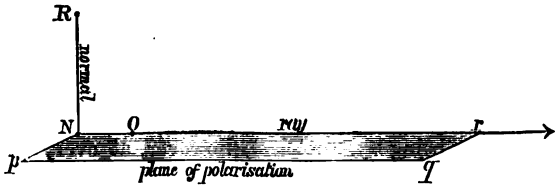

FIG. 1.

single given colour and given intensity, within a given medium, we have thus three characters to consider:—

1. The line of transmission of the ray,
2. The direction of the plane of polarisation,
3. The velocity of transmission.

The direction of a plane being most conveniently defined by the direction of its normal, the above three characters may be geometrically represented by means of two intersecting perpendicular lines, one of them definite in position, the other only in direction: and any definite function of the length of either may represent the velocity.

The direction of transmission $O\,r$, and the plane of polarisation $O\,p\,q\,r$

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of a given ray (Fig. 1), may thus be represented by two lines Or RN, where RN is any line perpendicular to the plane $Opqr$, and therefore also to the ray Or: the velocity of transmission may be represented by any function of either of the lines Or RN.

If O, a point on the ray, be given, and the normal of the plane of polarisation be taken to intersect the ray, all the characters may be represented by means of a *single line* RN, *not passing through the given point*: for the line Or is then known, since it passes through O and intersects RN perpendicularly.

The laws of ordinary reflection and refraction accounted for by an undulatory theory.

Two hundred years ago (1678-90), Huygens showed, by reasoning which is really independent of the physical nature of the periodic change, though he imagined it to be identical in character with that involved in the transmission of sound, that the laws of ordinary reflection and refraction of light are compatible with an undulatory theory. He assumed that a general disturbance of the ether at any given point must eventually produce disturbances at all other points of the medium, and that in a transparent body showing ordinary refraction the velocity of transmission of the disturbance is independent of the direction; all points on a spherical surface having the given point for centre are thus at any moment in a similar state of disturbance. If we have regard to the arrival of the disturbance from its origin, we may say that in this case the *front* of the disturbance at any epoch is a sphere. The front of the disturbance due to a single centre may, for the sake of brevity and generality, be called the *wave-surface*. If the disturbance at the centre be persistent and periodic, the surface which defines the front of the disturbance at a given epoch passes through points of the medium at which, notwithstanding the continual change at each point, there is persistent identity of phase of vibration.

Huygens gave a geometrical construction for the determination of the direction of the refracted ray by means of the spherical wave-surface, the direction being that of a line joining the point of incidence of the ray to the point of contact of a tangent plane of the wave-surface, drawn through a corresponding line which lies in the refracting surface and is normal to the plane of incidence: if v be the velocity in the first medium, i the angle of incidence of the ray, and the size of the sphere correspond to the lapse of a unit of time, the distance of the corresponding line from the point of incidence is $\frac{v}{\sin i}$.

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The laws of refraction of light by a crystal of calcite accounted for by an undulatory theory.

In the case of calcite, the refraction is in general not single but double. One of the rays, and only one, follows the laws of ordinary refraction for all directions: hence Huygens inferred that the surface of disturbance corresponding to this ray is the same as for ordinary media, namely a sphere. It was necessary to assume a different form of surface of disturbance to account for the extraordinary refraction of the other ray, and the surface which first suggests itself, after a sphere, is an ellipsoid: further, since the refraction of the second ray is the same for all directions equally inclined to a special direction in the calcite-crystal, or since rays lying in a plane perpendicular to this line obey the laws of ordinary refraction, it is necessary for the surface of disturbance to be one of revolution about that direction as axis. Testing this hypothesis and finding it satisfactory, Huygens inferred from his observations that the surface of disturbance corresponding to the second ray is really a spheroid, touching at the extremities of its axis the spherical surface of disturbance corresponding to the first ray. This relation between the surfaces has been confirmed by later experimenters and found to hold for other crystals analogous to those of calcite: it is undoubtedly a Law of Nature.[1]

The direction of the extraordinarily refracted ray is given by the same geometrical construction as before, the surface of disturbance being taken as a spheroid instead of a sphere.

The wave-surface is identical with the ray-surface.

Let *rs RS* (Fig. 2) be two wave-surfaces due to an origin *O*, and with the line *OrR* as axis describe a cone of small angle, determining areas *a b AB* upon them. There is great difficulty in imagining the exact nature of the physical process by which an isolated *ray* could be propagated through the ether by means of undulations: still the conception of a ray of light comes so naturally, and has been found so serviceable from the very earliest times, that rays, rather than waves, will be used throughout the present paper.

Having regard to the apparent rectilinearity of propagation within a homogeneous medium, we may reasonably assume that, if light is propagated by the disturbances of a medium and the disturbances at all parts of

[1] Stokes: *Proc. Roy. Soc.*, 1872, vol. 20, p. 443; *Comp. Rend.*, 1873, vol. 77, p. 1150. Abria: *Ibid.*, p. 814. Glazebrook: *Phil. Trans.*, 1880, vol. 171, part 2, p. 421. Hastings: *Amer. J. Sc.*, 1888, ser. 3, vol. 35, p. 60.

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the first surface are allowed to produce their effects at the second surface, the resultant disturbance of the area $A\,B$ is identical with that which would directly follow from a rectilinear transference of the disturbances at points on the area $a\,b$ to corresponding points on the area $A\,B$; and thus that the length Or, which represents the distance to which the front of disturbance has travelled in the direction Or in a given interval of time, also represents the velocity of transmission of a ray of light in the same direction. Regarded from this point of view, the surface of disturbance or wave-surface may be termed the *ray-surface*.

Ray-front.

Further, if a pencil of rays having OrR for axis starts simultaneously from O, the front of the pencil at a certain epoch is a portion of the ray-surface containing r, and at a subsequent epoch is a portion of the ray-

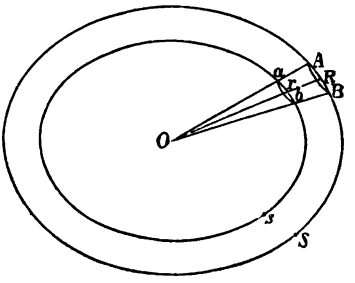

FIG. 2.

surface containing R: in the limiting case, where the pencil is of extremely small angle, its front is in the tangent planes at r and R at successive epochs. The plane front, which thus belongs to an extremely small pencil including a given ray, may be briefly denoted as the *ray-front* for that ray.

Since the ray-surface retains a constant similarity of form and position, for the ratio $OR : Or$ depends solely on the time, the tangent planes at R and r are parallel.

When the ray-surface is not a sphere, the tangent plane at any point is in general inclined obliquely to the radius vector drawn to the point from the origin, and a ray-front is then oblique to its corresponding ray.

In the case of calcite, the ray-surface has two sheets and consists of a sphere and a spheroid.

Huygens was thus led to the discovery that the laws of refraction in

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the case of calcite are consistent with an undulatory theory, if the velocities of transmission of rays of light within this mineral are determined by a sphere and a spheroid, touching each other in the axis of revolution of the latter.

If a line Or_2r_1 (Fig. 8), drawn from the common centre O, intersects the sphere and spheroid in r_2 and r_1 respectively, according to Huygens the velocity of transmission of one ray in the direction Or_2r_1 is measured by Or_2, and of the other by Or_1.

For a single direction of Or_2r_1, namely that of the axis of revolution $CO\overline{C}$, the two points r_2 and r_1 coincide, and the rays travel with equal velocity; this direction is called the *optic axis* of the crystal.

Plane-polarisation of each of the refracted rays

So far we have had regard merely to the relation of the two velocities to the direction of ray-transmission within the calcite-crystal. It did not escape the notice of Huygens, however, that each of the rays emergent from a crystal of calcite differs from ordinary light: the difference is one which he was unable to account for by his version of the undulatory theory. It was not till more than a century afterwards (1808) that Malus made the accidental discovery that the same change in the character of the light may be induced by reflection from a plate of glass: to this alteration, termed by Malus *polarisation*, the attention of physicists was largely directed during the immediately succeeding years.

If a plate of calcite be placed with its faces perpendicular to an aerially transmitted plane-polarised ray, the latter is in general divided at the first surface into two: the two rays travel through the plate in directions mutually inclined to each other, and, emerging from it, are transmitted through the air with the same direction as that of the original ray: each of the emergent rays is plane-polarised, but the planes of polarisation of the rays have not the same direction; they are, in fact, perpendicular to each other. Further, when the plate is turned round its normal through any angle, the plane of polarisation of each emergent ray is also displaced through exactly the same angle: the direction of the plane of polarisation is thus dependent on characters belonging to the plate itself: it is found to be independent of the direction of the plane of polarisation of the ray incident on the plate.

For one of the emergent rays, the line of transmission within the plate is continuous with the path of the ray before incidence and after emergence: as the position of the plane of polarisation of the emergent ray is independent of the thickness of the plate, we may reasonably assume, as

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before in the case of glass, that the ray transmitted *within the plate* is likewise plane-polarised, and that the plane of polarisation during such transmission is identical in direction with that of the *emergent* ray, thus rotating with the plate as the plate is turned round its normal.

As the emergent rays are indistinguishable from each other in character and only differ in the positions in space of their planes of polarisation, we may likewise assume that the second emergent ray is also transmitted within the plate as a plane-polarised ray, but with a direction of plane of polarisation perpendicular to that of the first.

It will be found that the characters of rays which have been transmitted through a plate of calcite can be accounted for, if we imagine that in such a medium a plane-polarised ray transmissible in any given direction has its plane of polarisation in one or other of two rectangular positions, which depend on the crystal itself.

As in the case of air, glass, and analogous media, the periodic change of the ether at every point of a plane-polarised ray transmitted within any bi-refractive medium may be assumed to be dissimilarly symmetrical to two perpendicular planes; but it may be remarked that it is only the *disturbed* ether which is assumed to be dissimilarly symmetrical in the distribution of its characters.[1]

The plane of polarisation is related to the radius vector of the ray-surface.

Malus[2] discovered that the direction of the plane of polarisation of any ray transmitted within a crystal of calcite is determined by the direction of the corresponding radius vector of the ray-surface: he showed that the plane of polarisation for the ray Or_1 (Fig. 3) corresponding to the spheroid is always perpendicular to the plane Or_1C, which contains the ray-direction and the optic axis, and for the ray Or_2 corresponding to the sphere is the plane Or_2C, which also contains the ray-direction and the optic axis: in other words, the plane containing the ray-direction and the optic axis is the plane of polarisation of the ray belonging to the sphere and the transverse plane of the ray belonging to the spheroid.

The above might have led to the recognition of the possible existence and the optical characters of biaxal crystals.

The above facts and reasoning were known to physicists before the existence of biaxal crystals had been discovered; further, the reasoning is really independent of the physical nature of the vibratory change which constitutes light. We proceed to prove that though the geometrical

[1] See also pages 283, 355.

[2] *Mém. prés. à l'Institut:* Paris, 1811, vol. 2, p. 413

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representation of the laws of transmission of light in biaxal crystals was suggested to Fresnel by ideas in which elasticity had a great part, the possible existence of such crystals, and the corresponding laws of transmission of light, might have been deduced from the above by a simple generalisation, involving no reference either to the constitution of the luminiferous ether or to the nature of the physical change involved in the transmission of light; and further, that the step was so natural a one to take that the discovery of the true form of the wave-surface for biaxal crystals could scarcely have been long avoided.

Another mode of geometrically representing the characters of the extraordinarily refracted ray, by reference to the same spheroid, naturally presents itself.

Draw OR_1 parallel to r_1V (Fig. 3), the tangent at r_1 to the ellipse in

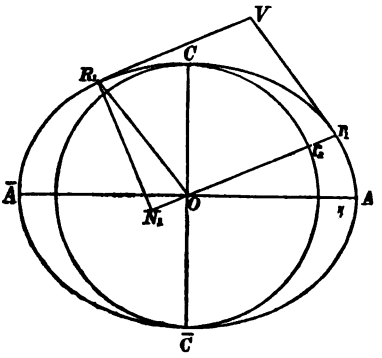

FIG. 3.

which the spheroid is cut by the plane r_1OC; OR_1 and Or_1 are said to be conjugate to each other, and the tangent at R_1 is parallel to Or_1. By a well-known property of the ellipse, the area of the parallelogram of which OR_1 Or_1 are adjacent sides is constant, whatever the direction of Or_1: hence the area is $OA \cdot OC$; OA and OC being the principal axes of the ellipse, and therefore conjugate to each other. But if R_1N_1 is perpendicular to Or_1, meeting it in N_1, and is thus normal to the ellipse and therefore also to the spheroid at R_1, the area of the parallelogram is also $Or_1 \cdot R_1N_1$.

Hence $Or_1 = \dfrac{OA \cdot OC}{R_1N_1}$, whatever the direction of Or_1.

In other words, the *velocity* of a ray transmitted in the direction Or_1 may be represented, not only by Or_1, but by the inverse of R_1N_1. But the

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same line R_1N_1 determines the *plane of polarisation* of the ray Or_1, for as already stated, the line R_1N_1 is normal to that plane. Further, the same line R_1N_1 determines the *direction* of the ray, for the ray passes through O and is perpendicular to R_1N_1.

Hence the direction, velocity and plane of polarisation of the ray Or_1 can all be represented by means of a single corresponding line R_1N_1, which is at once normal to the spheroid and the ray.

This mode of representation naturally presents itself *as soon as the plane of polarisation is indicated by its normal;* in fact, any attempt to represent geometrically the observed facts of the double refraction of calcite almost inevitably leads to it.

The same mode also suffices to represent the characters of the ordinarily refracted ray without necessitating the use of a second surface.

But for any radius vector Or_1 of a spheroid there are always *two* normals of the spheroid which intersect it perpendicularly: one of them has just been indicated, namely R_1N_1; the other is normal to the plane r_1OC, at the centre of the spheroid, and therefore always lies in the equatorial plane. As already stated, the *plane of polarisation* of the ray Or_2 is r_2OC or r_1OC: and the normal of its plane of polarisation thus lies in the equatorial plane, and is normal both to the spheroid and the ray. Further, the intercept made by the ray Or_2 upon this normal of the spheroid is OA, whatever the direction of Or_2r_1: hence, if the same law as before holds for the relation of the velocity to the intercept upon the normal of the spheroid, the velocity of the ray Or_2 is $\frac{OA \cdot OC}{OA}$, or OC; and this is exactly the velocity required.

Hence the velocity and plane of polarisation of the ray Or_2 can likewise be represented by means of a corresponding line which is at once normal to the spheroid and the ray: and this line indicates the plane in which the ray having these characters will lie.

The characters of the refracted rays can be simply expressed by reference to the spheroid alone.

All the characters of rays transmitted in various directions through a crystal of calcite may thus be simply expressed by means of a *single* surface, the spheroid. The relation of the optical characters of the crystal to the geometrical characters of the spheroid is as follows:—

To every given point on a single surface, a spheroid, there in general corresponds one ray: the *direction* of the ray is that of a diameter

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intersecting perpendicularly the normal drawn at the point to the spheroid; the *velocity* of the ray is inversely proportional to the length of the normal intercepted between the surface and the ray; the *plane of polarisation* of the ray is perpendicular to the same normal.

For points of the spheroid lying on the equatorial circle or at the ends of the axis of revolution, the normal passes through the centre, and the direction of the ray becomes indeterminate: such a point may be regarded as the limiting case of a small circle; and thus corresponds, not to a single ray, but to an infinity of rays lying in a plane perpendicular to the normal, all transmitted with the same velocity, and all having the same plane of polarisation.

In the case of singly refractive substances there is a spherical surface of reference for which the same general relations are true.

Generalisation.

But it immediately suggests itself that in the case of a crystal like barytes, of which the morphological development and the physical characters are dissimilarly symmetrical to three rectangular planes, the surface of reference, if such a surface exists, is more likely to be an ellipsoid with three unequal axes than an ellipsoid of which two axes are equal. In fact, the correspondence of the optical and the morphological symmetry of crystals was announced by Brewster in 1819.

In the fourth Section are deduced the laws of transmission of light in a crystal for which the surface of reference is an ellipsoid having three unequal axes; starting with the hypothesis that the relations between the geometrical characters of the surface of reference and the optical characters of the medium are identical with those which have just been found to obtain when the surface of reference is either a spheroid or a sphere.

The Optical Indicatrix.

To the surface of reference the term *Optical Indicatrix* may be assigned: this suggestive term has the advantage of being equally applicable whether the surface of reference is an ellipsoid, a spheroid, or a sphere, and it is independent of all versions of the undulatory theory; the adjectival prefix may be omitted when the term Indicatrix involves no ambiguity. The Indicatrix is identical in form with the *ellipsoid of elasticity* of various authors, the *ellipsoid of polarisation* of Cauchy, the *ellipsoid of indices* of Mac Cullagh, and the *index-ellipsoid* of Liebisch.

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Relation of the optical indicatrix to the general symmetry of the crystal.

In regard to the arrangement of its faces, every crystal is found to belong to one or other of six types of symmetry, distinguished as cubic, tetragonal, hexagonal, ortho-rhombic, mono-symmetric, and anorthic: further, it has been demonstrated by the mathematician that the types of crystalline symmetry thus met with are precisely those which are presented by systems of planes of which the relative positions can be expressed by means of whole numbers, a law to which the faces of crystals are found to conform. Further, we are led by experiment to the induction that a type of symmetry is such, not only for the arrangement of the faces of a crystal, but for all the physical characters: the planes of symmetry characteristic of the types are thus planes of *general symmetry*.

On the other hand, a plane may be one of symmetry for a particular character without being a plane of general symmetry of the crystal: the type is thus not necessarily determinable from the symmetry of the crystal with respect to a single character. For example, a crystal may have the six faces of a cube and really belong, not to the cubic, but to the tetragonal, or even the ortho-rhombic type; observation of some character other than the geometrical being thus necessary to the distinction: again, a plane inclined at any angles to the planes of general symmetry of a cubic crystal, and any plane containing the morphological axis of a tetragonal or hexagonal crystal, is a plane of symmetry for the changes produced by dilatation on change of temperature, and is generally not a plane of symmetry for the facial arrangement.

The above induction requires a plane of general symmetry to be a plane of symmetry of every indicatrix: on the other hand, a plane of symmetry of an indicatrix is not necessarily a plane of general symmetry of the crystal.

Hence, if the most general form of the indicatrix be an ellipsoid, it will follow that in the case of an ortho-rhombic crystal the axes of any indicatrix must coincide with the three axes of general symmetry. For a tetragonal or hexagonal crystal, the symmetry of the indicatrix with respect to the general planes of symmetry requires two of the axes of the ellipsoid to be equal, and the ellipsoid to be one of revolution about the morphological axis. For a cubic crystal, the symmetry of the indicatrix with respect to the general planes of symmetry necessitates the equality of all the axes of the ellipsoid, and the surface becomes a sphere.

The above is true for all colours of the light, though the relative magnitudes of the axes, both for the general ellipsoid and the ellipsoid of revo-

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lution, may vary with the colour: further, it is true for all temperatures of the crystal consistent with the stability of the structure, for a plane of general symmetry must retain that character between the assumed limits of temperature.

In the case of a mono-symmetric crystal, the induction still requires the plane of general symmetry to be a plane of symmetry of the indicatrix for all colours of light and for all temperatures consistent with crystalline stability; but the positions and dimensions of the two axes of the ellipsoid lying in the plane of general symmetry are otherwise independent of the latter, and will in general vary both with the colour of the light and the temperature of the crystal.

And in the case of an anorthic crystal, in which there is a centre, but no plane, of general symmetry, the positions and dimensions of all three rectangular axes of the indicatrix corresponding to a given colour or temperature are free from limitations by a plane of general symmetry, and will likewise vary both with the colour of the light and the temperature at which the determinations are made.

Section III.—Naturalness of the method.

Objections.

To the above reasoning, by which it is sought to prove that in the case of calcite the reference of the two sheets to the spheroid alone is one which it is natural to make, and not a mere geometrical artifice only to be discovered after the truth of the generalisation has been established, it may be objected that the reference would in such case have been made long before the present century. It must be remembered, however, that the consequent generalisation would have been a barren speculation at a time when the polarisation of light by reflection was still undiscovered (1808), and the optical characters of most doubly refractive crystals were still beyond the powers of observation; indeed, it was not till the decade 1810-20 that any series of numerical data were available for the testing of

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a theory: even the accuracy of the construction given by Huygens for the determination of the directions of the refracted rays in calcite was discredited by most physicists at the beginning of this century.

But it may be fairly objected that if the above reference and generalisation be natural, the discovery of the process would have preceded the development of any elastic theory of double refraction. And, in fact, it was really by a process of generalisation that Fresnel's discovery of the true form of the ray-surface for biaxal crystals was made. When the above argument was written, the detailed history of Fresnel's theory had not come to the notice of the author: as the facts are not generally known, and have an important bearing on the true significance of the elastic theory of double refraction, it becomes desirable to explain the position.

The development of Fresnel's theory.

Fresnel's celebrated memoir on Double Refraction was not printed till 1827: in that year, and before the issue of the memoir, Fresnel died at the early age of 39, after years of illness. In the memoir are incorporated papers submitted to the Academy at different dates in the years 1821 and 1822, and it occupies no less than 132 pages of large size. For the sake of brevity, Fresnel made many omissions from the papers as originally submitted to the Academy, and for the sake of clearness adopted a synthetic mode of treatment: the result is that the memoir as printed gives no clue to the real order of discovery, and the reader is apt to infer that Fresnel discovered the true form of the ray-surface *a priori* by means of equations relative to the elastic forces evoked by the disturbance of an incompressible elastic ether. The following statement by Aldis[1] exemplifies this, which is still a very general impression:—

"Fresnel's theory is undoubtedly not a sound dynamical theory. It has, however, the great merit of representing accurately the facts of double refraction as far as experiment at present has tested them, and in one instance has led to the discovery of facts (the conical refractions) previously unobserved. Probably, when the Newton of Physical Optics has succeeded in linking together all the phenomena of Light into one continuous chain, the name of Fresnel will yet be remembered with a reverence akin to that which astronomers feel for Copernicus and Kepler."

The real order of development was of course known to some of Fresnel's

[1] W. S. Aldis. *A Chapter on Fresnel's Theory of Double Refraction.* Cambridge, 1870, p. 26.

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contemporaries, but to the next generation it was a mystery; it was not till forty years after Fresnel's death that the mystery was dispelled by the publication of the original memoirs, which had been carefully preserved in the family. Verdet,[1] one of the editors of Fresnel's collected papers, makes the following remarks:—

"It may seem odd that reasoning which is incomplete and inexact in two points should have for result one of the best confirmed of the Laws of Nature. But we have seen that this law became manifest to Fresnel as the result of a generalisation quite similar to the generalisations which have led to most great discoveries. When he wished afterwards to account for the law by a mechanical theory, it is not astonishing that he should have led the theory, perhaps unwittingly, towards the end which he already knew of, and that, in his choice of hypotheses, he should have been determined, less by their intrinsic probability, than by their agreement with what he was justified in believing to be true. We have seen some traces of the progress of his ideas in the marginal notes which he had added to the manuscript of memoir No. 38, a memoir here printed for the first time. In the later memoirs we find nothing but the explanation, in different forms, of the mechanical theory by which he tried to demonstrate *a posteriori* the laws which direct intuition had revealed to him."

After this clear statement on the part of his editor, it is obvious that Fresnel's theory of double refraction, however ingenious, has no claim to credit for its predictions: the latter are really a direct consequence of the generalisation which had preceded the theoretical development of the vibratory properties of an elastic but incompressible ether.

Preliminary attempts at generalisation.

The first attempt at the generalisation of Huygens' construction had suggested a sphere combined with a concentric ellipsoid having three unequal axes as the most general form of ray-surface: this assumed that in the most general case one of the rays obeys the ordinary laws of refraction.

It was found, however, that the refraction of the second ray as experimentally determined is inconsistent with an ellipsoidal form of ray-surface. Nor would such a combination of ray-surfaces account for the optical characters of a biaxal crystal: for if a concentric sphere and ellipsoid meet each other, they must either touch at the extremities of a principal diameter, or intersect in two curves; in the former case there would be only one direction of equal ray-velocity; in the latter case this

[1] *Œuvres Complètes d'A. Fresnel*: Paris, 1868, vol. 2, p. 327.

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character would belong to every diameter which passes through the curves of intersection, and thus to an infinity of lines lying on the surface of a cone.

In 1819 Biot made the important discovery that the results of optical measurement are consistent with two empirical laws, both of them reached by processes of generalisation: in combination with the assumption that one of the rays obeys the laws of ordinary refraction, they completely express the polarisation and velocity of the second ray in terms of its direction in the crystal.[1]

1st law. We have seen that in the case of a uniaxal crystal, two rays transmitted along any given direction had been shown by Malus to have their planes of polarisation respectively coincident and at right angles with the plane containing the ray-direction and the optic axis: from this Biot was led by generalisation to the discovery that in the case of a biaxal crystal the planes of polarisation are the internal and external bisectors of the angle between the two planes which contain the ray-direction and pass each through one of the optic axes.

2nd law. In the case of a uniaxal crystal, if v_1 and v_2 be the velocities of transmission of the two rays transmissible in a direction inclined at an angle σ to the optic axis, it follows from Huygens' construction that the ratio $\left(\frac{1}{v_1^2}-\frac{1}{v_2^2}\right):\sin^2\sigma$ is constant for all directions: noticing this, Biot was led by generalisation to the discovery that in the case of a biaxal crystal the ratio $\left(\frac{1}{v_1^2}-\frac{1}{r_2^2}\right):\sin\sigma_1\sin\sigma_2$ is constant, σ_1 σ_2 being the inclinations of the ray to the optic axes.

The second law, combined with the assumption that the velocity of one of the rays is independent of its direction, leads to a surface of the fourth degree, tangent to a concentric sphere at the ends of two diameters, as the ray-surface corresponding to the second ray.

For, let $l\ 0\ n\ \bar{l}\ 0\ n$ $\lambda\ \mu\ \nu$ be direction-cosines of the optic axes and of the second ray respectively (Fig. 9):

$$\text{then } \cos\sigma_1 = l\lambda + n\nu, \text{ and } \cos\sigma_2 = -l\lambda + n\nu.$$

If r be the variable velocity of the second ray, and a be the constant velocity of the first ray, it follows from the above law that

$$\frac{1}{r^2}-\frac{1}{a^2} = k\sin\sigma_1\sin\sigma_2,$$

where k is a constant.

[1] *Mémoires de l'Acad. de l'Institut de France*, 1820, vol. 3, pp. 228, 233.

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Hence $\frac{1}{k^2}\left(\frac{1}{r^2}-\frac{1}{a^2}\right)^2=(1+\cos\sigma_1)(1-\cos\sigma_1)(1+\cos\sigma_2)(1-\cos\sigma_2)$.

Substituting the values of $\cos\sigma_1$ and $\cos\sigma_2$, and writing $\lambda=\frac{x}{r}$, $\mu=\frac{y}{r}$, $\nu=\frac{z}{r}$, we have for the equation of the second ray-surface,

$$\frac{1}{k^2}\left(1-\frac{r^2}{a^2}\right)^2=(lx+nz+r)(lx+nz-r)(lx-nz+r)(lx-nz-r),$$

an equation of the fourth degree. The second ray-surface meets the first ray-surface ($r=a$) at the intersection of the latter with the four planes, $lx\pm nz\pm a=0$, and these planes are tangent to the sphere at the extremities of the optic axes: hence the two surfaces are tangent to each other at the same points.

The history of the ray-surface.

At the advent of Fresnel, the emissive theory of light still held almost undisputed sway in the scientific world, notwithstanding the interference discoveries which had been made by Dr. Thomas Young, many years before. Convinced that the true explanation of interference was furnished by the undulatory theory, Fresnel devoted himself with ardour to its theoretical and experimental development, in which he had to sustain the attacks of Laplace, Poisson and Biot, who were firm believers in the truth of the older theory. After successful explanation of diffraction and of the polarisation-colours of thin plates on the undulatory hypothesis, Fresnel in 1821 attempted to solve the problem of double refraction.

Young had already suggested (12 Jan. 1817) that the vibrations of the luminiferous ether are motions transverse to the ray, and had compared the transmission of a ray of light to the transmission of a transverse vibration along a stretched cord:[1] Fresnel himself, in conjunction with Arago, had shown experimentally that two rays polarised in perpendicular planes are incapable of mutual interference, thus confirming the idea that the motion of the ether of a plane-polarised ray is wholly perpendicular to the direction of transmission, so long, at least, as the medium is singly refractive.

Fresnel therefore suggested that the difference of velocities of the two rays transmissible in the same direction in a doubly refractive medium may be due to differences of elastic force evoked by equal displacements of ethereal particles in different directions: the same suggestion had been

[1] *Œuvres Complètes d'A. Fresnel:* vol. 1, p. 634; vol. 2, p. 742.

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published by Young[1] in 1809, before the idea of transverse vibrations had presented itself. Assuming that the ethereal elasticity, in the case of a uniaxal crystal, is the same for all directions of displacement perpendicular to the optic axis, and different from that evoked by displacements parallel to it, and that the vibrations are always *perpendicularly* transverse to the ray[2] (an assumption he departed from later), Fresnel showed that the vibration of the ordinary ray must be perpendicular to its plane of polarisation; for in this case the vibration, being always perpendicular to the optic axis, evokes an elastic force of which the magnitude is the same whatever the direction of the ray. The vibration of the extraordinary ray being likewise assumed to be perpendicular both to the ray and its plane of polarisation, the elastic force evoked by it will vary with the direction of the vibration, and thus the velocity will depend on the inclination of the ray to the optic axis.

But Fresnel[3] soon saw that, if such an explanation is true, neither of the rays transmitted in a biaxal crystal can have a velocity independent of the direction, for in such a crystal there is no direction such that the optical characters are the same in all directions equally inclined to it. Having submitted this inference to the test of experiment, Fresnel announced its confirmation in September 1821, thus completely upsetting the ideas which then prevailed as to the forms and relations of the two ray-surfaces of a biaxal crystal.

Further developing the theory, Fresnel[4] showed (November 19, 1821) that if the ethereal elasticity be proportional to the square of the velocity, as in the case of the longitudinal vibrations of an elastic medium, a surface such that any radius vector represents the square of the elastic force evoked by a unit displacement in its direction is, in the case of a uniaxal crystal, a spheroid (distinct from the spheroidal ray-surface itself), *if the double refraction is small.* Conversely, lines measured in a direction perpendicular to a diametral plane of the auxiliary spheroid, and having lengths equal to the maximum and minimum radii vectores of the section, would *approximately* represent the velocities with which vibrations, parallel to those radii vectores, would be transmitted along the normal of the plane.

It then suggested itself to Fresnel that an ellipsoid with three unequal axes might be a more general form of this surface of elasticity, and that the same construction might hold for the determination of the *approximate* velocities of the rays having a given direction. The two circular

[1] *History of the Inductive Sciences*; by Whewell: London, 1857, vol. 2, p. 329.

[2] *Œuvres Complètes d'A. Fresnel:* vol. 2, p. 281.

[3] *Ibid.*, p. 257.

[4] *Ibid.*, pp. 285, 304, 306.

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sections of the ellipsoid immediately account for the existence of two optic axes, for there will be only one velocity of transmission along their normals: again, the planes of polarisation for a given ray-direction are at right angles, for the corresponding vibrations are parallel to the axes of the diametral section perpendicular to the common direction. It remained to discover whether the two empirical laws established by Biot were geometrically consistent with the form of ray-surface suggested by the above construction: and this being found by Fresnel to be very approximately the case, the true form of ray-surface was at last determined.

In this way, however, it presented itself as an approximation, true only when the double refraction is small: it was not till later (26 Nov. 1821) that the hypothetical form of the surface of elasticity[1] was changed from an ellipsoid to a surface of the fourth degree: with this hypothesis the ray-surface already obtained as an approximation appeared as the true ray-surface, independently of the amount of the double refraction of the medium.

It follows from the above that Fresnel's discovery of the form of the ray-surface for biaxal crystals was really arrived at by a geometrical generalisation of Huygens' ray-surface for uniaxal crystals, and that the geometrical relation used in the generalisation was suggested by the conception of a plane-polarised ray as due to vibratory motion perpendicular to its direction.

The true nature of the luminiferous ether.

Notwithstanding the success with which so many optical properties have been explained on the hypothesis that light is a vibratory motion of an elastic ether of which the effective density depends on the permeated matter, it would be wrong to infer that light is *actually* due to such a vibratory motion. It is conceivable that other hypotheses may likewise lead to similar results: and, indeed, any other quantities about which the same general assertions may be made and which obey the same mathematical laws will satisfy the equations and furnish other analogies. In fact, Gibbs[2] has lately shown that the equations which result from the last version of the elastic theory have a corresponding electrical interpretation.

Again, according to Clerk Maxwell, light is not a vibratory motion due to elasticity, but an electro-magnetic vibration (whatever that may be); and he showed that the velocity of transmission of electro-magnetic action in

[1] *Œuvres Complètes d'A. Fresnel:* vol. 2, p. 338.

[2] *Phil. Mag.* 1889, ser. 5, vol. 27, p. 238.

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free ether is identical with that of light. The recent experiments of Hertz have placed the undulatory character of electro-magnetic radiation beyond the region of hypothesis, and it is now experimentally established that electro-magnetic waves and light-waves differ only in length; while the wave-length for sodium-light is ·000589 millimetres, the short electro-magnetic waves produced by Hertz had still a length of 2 metres. On the other hand, it seems that electro-magnetic actions are inexplicable as mere vibratory motion of an elastic ether: Professor Fitzgerald,[1] who has given much thought to the mechanical representation of the ether, points out that "if magnetic forces are analogous to the rotation of the elements of a wave, an ordinary solid cannot be analogous to the ether, because the latter may have a constant magnetic force existing in it for any length of time, while an elastic solid cannot have continuous rotation of its elements in one direction existing within it."

The educational difficulty.

Taking everything into consideration, it seems undesirable, from the purely educational point of view, to continue such a synthetic mode of treatment as was adopted by Fresnel in the memoir of 1827. The subject of the optical properties of crystals is so extensive that it is unsatisfactory to make all the laws appear to depend upon an hypothesis of the truth of which we are not convinced: otherwise it becomes necessary either to keep the student in ignorance of the doubts as to the truth of the hypothesis, or to raise a feeling of distrust as to the accuracy of every deduction therefrom. It would seem better to develop the subject by means of analogy and experiment, and to assign a subordinate importance to the mechanism of the ether.

Three other modes of generalisation.

In addition to the method explained in the last Section there are at least three others by which a generalisation of Huygens' construction may be arrived at. One of them depends on the fact that the wave-surface is an envelope.

If Of_2f_1 (Fig. 4) be any line intersecting the sphere and spheroid, and we consider a section of the surface by a plane containing the optic axis and the given line, it follows that $Of_1 = \frac{OA \cdot OC}{OR_1}$, where OR_1 is per-

[1] *Nature*, 1890, vol. 42, p. 173.

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pendicular to Of_1, and that Of_2 is equal to OC or $\frac{OA \cdot OC}{OA}$. Hence the lines Of_1 Of_2, which represent the velocities of the wave-fronts $f_1 r_1 f_2 g$, are inversely proportional to the lines OR_1 and OA, or to the axes of the ellipse in which the spheroid is intersected by a plane parallel to the wave-fronts $f_1 r_1 f_2 g$,.

Huygen's wave-surface is thus the envelope of planes which are parallel to the same central section of the spheroid, and pass through those two points on the common central normal which are distant from the centre by lengths inversely proportional to the axes of the section. On generalising this result, by the substitution of an ellipsoid with three unequal axes for the spheroid, Fresnel's wave-surface is obtained:

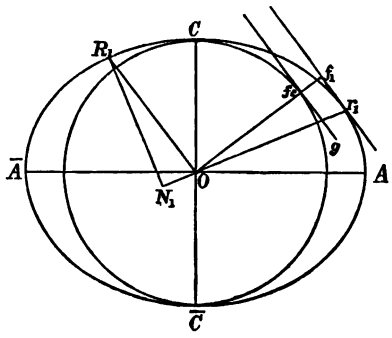

FIG. 4.

this generalised construction is virtually identical with the one employed by Fresnel in the memoir of 1827; the only difference being that he used the inverse of the ellipsoid instead of the ellipsoid itself.

The two other geometrical constructions, which present themselves for the generalisation of Huygens' construction, only appear indirectly: they depend on corresponding relations between the rays or ray-fronts and the *polar reciprocal of the indicatrix*.

Advantages of the method here suggested.

There are thus two purely geometrical processes, which *directly* present themselves for trial as being possible modes of representing the optical characters of those crystals which belong to a lower type of general symmetry than the uniaxal; both lead to identical results. If we are

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compelled to select one or other of these processes for use as an educational instrument, there can be no doubt on which the choice must fall.

The method based on an envelope is so far wanting in simplicity that Fresnel himself gave no rigorous solution of the equations: this was supplied by Ampère, and it was not till even a decade later that the less complicated mode of elimination, now generally given, was invented by Archibald Smith. Further, the construction yields the wave-surface in such a way that its singularities are not obvious, and were only remarked by Sir William Hamilton several years after Fresnel's death.

On the other hand, as was shown in Section II, the geometrical basis here advocated naturally suggests itself as soon as any attempt is made to represent geometrically the observed optical properties of uniaxal crystals: we shall further show that it readily furnishes the equation of the ray-surface without demanding any knowledge of the differential calculus or any determination of maxima and minima; that it immediately suggests all the singularities of the ray-surface; and that, in fact, most optical problems are reduced to a form in which their solution can be effected by the elementary geometry of the ellipsoid. We may add that the employment of an additional ellipsoid, the polar reciprocal of the first, is rendered unnecessary, and a continual source of confusion to the student is thereby removed.

Section IV.—Deduction of the Optical Characters corresponding to an ellipsoidal indicatrix.

General Relation.

The characters of a ray of plane-polarised homogeneous light transmitted within a medium are indicated by geometrical characters at a corresponding point on an ellipsoid; the direction of the ray is that of a diameter intersecting perpendicularly the normal drawn to the ellipsoid at the corresponding point; the velocity is inversely proportional to the length of the normal intercepted by the ray; the plane of polarisation is perpendicular to the normal.

It is required to deduce the relations of the optical characters for different directions in the medium.

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The order of deduction is as follows:—

Arts. 1-15 relate to *rays* in general; Arts. 16-20, to the particular ray-directions here termed *bi-radials;* Arts. 21-40, to *ray-fronts* in general; Arts. 41-44, to the particular front-normals here termed *bi-normals;* Arts. 45-52, to the *bi-radial* and *bi-normal cones.*

1. The construction of the ray-surface.

Let $a^2x^2 + b^2y^2 + c^2z^2 = 1$ be the equation of the indicatrix; a, b, c being in descending order of magnitude: O the centre of the indicatrix: $x'\ y'\ z'$ the co-ordinates of R, a point on the indicatrix: NOr a line intersecting the normal RN perpendicularly (Fig. 5).

According to the above relation, the *direction of the ray* corresponding to the point R of the indicatrix is given by the line NOr, the *velocity* of the ray is measured by $\frac{1}{RN}$: the *plane of polarisation* is perpendicular to RN.

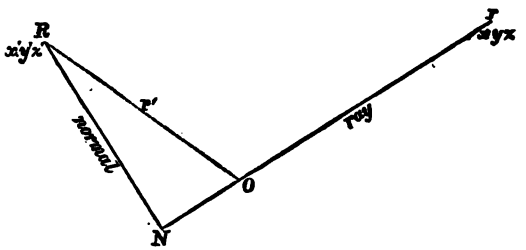

FIG. 5.

Take the length Or equal to $\frac{1}{RN}$: the locus of the points r, corresponding to all positions of R on the indicatrix, will be the *ray-surface* of the medium for the given simple colour: since the velocity of transmission of a ray of light of that colour along any radius vector of the surface is measured by the length of the radius vector.

The propositions of the present Section are stated in a form which is independent of any particular version of the undulatory theory: it may be remarked, however, that according to the latest version of the elastic theory, RN is the *direction of vibration* for the ray Or; according to Fresnel's version of the elastic theory and the present statement of the electro-magnetic theory, the direction of vibration is RO.[1]

[1] *Philos. Magazine*, 1888, ser. 5, vol. 26, p. 528: *Electricity and Magnetism, by J. Clerk Maxwell*; Oxford, 1881, vol. 2, p. 404; *Nature*, 1890, vol. 42, p. 174.

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2. *The symmetry of the ray-surface.*

From the mode of construction, it is evident that the planes of symmetry of the indicatrix are also planes of symmetry of the ray-surface.

3. *The sections of the ray-surface by the planes of symmetry.*

The section of the ray-surface by each plane of symmetry consists of a circle and an ellipse; the radius of the circle is the inverse of that axis of the indicatrix which is perpendicular to the plane of the section; the ellipse is similar and similarly situated to the section of the indicatrix by the same plane. This may be proved as follows:—

Let $AO\bar{A}$, $BO\bar{B}$, $CO\bar{C}$, be the principal axes of the indicatrix, and $OA = \frac{1}{a}$, $OB = \frac{1}{b}$, $OC = \frac{1}{c}$: it is required to determine the section of the ray-surface by one of the planes of symmetry, say AOC (Fig. 6).

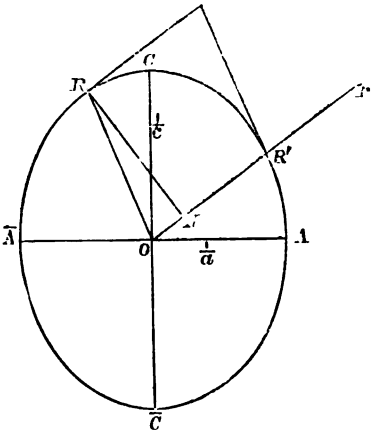

FIG. 6.

a. By considering a series of points in a small ring surrounding the point B on the indicatrix, it is seen that in the limit the point B itself corresponds, not to one ray, but to an infinity of rays, all lying in the plane AOC; for the axis OB is the normal of the indicatrix at B, and intersects perpendicularly all radii vectores of the indicatrix which lie in the plane AOC. Further, the length of the normal at B intercepted by each of the rays is OB: hence the velocity of each ray corresponding to the point B is $\frac{1}{OB}$ or b, and a circle of radius b, situated in the plane AOC, is on the ray-surface (Fig 7c).

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b. For a point R on the indicatrix, lying in the plane AOC, the normal RN of the indicatrix lies in the plane AOC, and is also normal at the point R to the elliptic section $AC\bar{A}\bar{C}$: if ONr is perpendicular to RN and $Or = \frac{1}{RN}$, Or is by construction a radius vector of the ray-surface (Fig. 6).

If R' be a point in which Or intersects the indicatrix, OR and OR' are conjugate to each other, for Or being perpendicular to RN is parallel to the tangent of the ellipse at R: hence the product $OR' \cdot RN$, which measures the area of the parallelogram of which OR OR' are adjacent sides, is constant, and equals the product $OA \cdot OC$ or $\frac{1}{ac}$.

Hence, $Or = ac\ OR'$

The locus of r is thus an ellipse, similar and similarly situated to the ellipse $AC\bar{A}\bar{C}$, and having ac times its dimensions: its semi-axis in the line OA will thus be c, and its semi-axis in the line OC will be a (Fig. 7c).

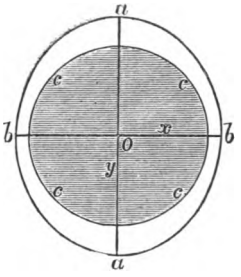

FIG. 7A.

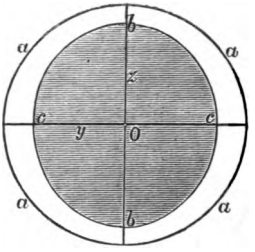

FIG. 7B.

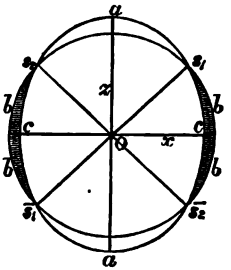

FIG. 7C.

c. To any ray lying in the plane AOC no other normal of the indicatrix is perpendicular: hence no radius vector of the ray-surface, other than the above, lies in the plane AOC; the circle $z^2+x^2=b^2$ and the ellipse $\frac{z^2}{a^2}+\frac{x^2}{c^2}=1$ are thus the only curves of intersection of the ray-surface with the plane AOC (Fig. 7c).

d. And the section of the ray-surface by the plane of symmetry BOA is a circle $x^2+y^2=c^2$ and an ellipse $\frac{x^2}{b^2}+\frac{y^2}{a^2}=1$ (Fig. 7A).

e. Similarly, the section of the ray-surface by the plane of symmetry COB is a circle $y^2+z^2=a^2$, and an ellipse $\frac{y^2}{c^2}+\frac{z^2}{b^2}=1$ (Fig. 7B).

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f. On consideration of the relative magnitudes of a, b, c, it will be seen that in one of the planes of symmetry the circle falls wholly within the ellipse; in another, the ellipse falls wholly within the circle; in the third, containing the longest and shortest axes of the indicatrix, the circle and ellipse intersect each other in four points lying at the extremities of two diameters $s_1 \bar{s}_1$, $s_2 \bar{s}_2$.

g. For any direction of ray lying in a plane of symmetry, there are thus two possible directions for the plane of polarisation, perpendicular to each other; and in general each plane of polarisation corresponds to a different velocity of transmission in the given direction. For two directions of the ray, those of the diameters $s_1 \bar{s}_1$, $s_2 \bar{s}_2$, the two velocities are equal (Fig. 7c).

If $x\,0\,z$ be the co-ordinates of one of the points s, we have

$$\frac{x^2}{c^2} + \frac{z^2}{a^2} = 1 \text{ and } x^2 + z^2 = b^2 : \text{ hence}$$

$$\frac{x^2}{c^2(a^2 - b^2)} = \frac{z^2}{a^2(b^2 - c^2)}.$$

If $\lambda\,0\,\nu$ be the direction-cosines of a diameter Os, the relation may also be written as

$$\frac{a^2\lambda^2}{b^2 - a^2} + \frac{c^2\nu^2}{b^2 - c^2} = 0.$$

The angle s_1OC is given by the relation

$$\tan s_1OC = \frac{c\sqrt{(a^2 - b^2)}}{a\sqrt{(b^2 - c^2)}} = \sqrt{\frac{\left(\frac{1}{a^2} - \frac{1}{b^2}\right)}{\left(\frac{1}{b^2} - \frac{1}{c^2}\right)}}.$$

h. In each of the planes OBC OCA OAB a plane-polarised ray is thus transmissible with the velocity a b or c respectively, whatever its direction in the plane: hence, by the general principle of undulations, the refraction of these rays by a surface perpendicular to the symmetral plane will be ordinary, and the index of refraction will be $\frac{v}{a}$, $\frac{v}{b}$, $\frac{v}{c}$ respectively; v being the constant velocity of transmission in the other medium. If $\alpha\,\beta\,\gamma$ be the values of the index of refraction of the rays in each of the above planes, for which the index of refraction is independent of the direction, we must have

$$a : b : c = \frac{1}{\alpha} : \frac{1}{\beta} : \frac{1}{\gamma};$$

$\alpha\,\beta\,\gamma$ are termed the *principal indices of refraction*.

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4. *Given the co-ordinates $x'y'z'$ of R, to find the velocity r of the corresponding ray Or.*

The velocity of the ray Or is measured by $\frac{1}{RN}$ (Fig. 5): but RN, being the normal of the indicatrix at the point R and perpendicular to ON, by construction is equal to the perpendicular drawn from the origin O to the plane $a^2x'x + b^2y'y + c^2z'z = 1$ which touches the indicatrix at R. If p be the length of this perpendicular

$$\frac{1}{p} = \sqrt{(a^4x'^2 + b^4y'^2 + c^4z'^2)}.$$

Hence $$r^2 = \frac{1}{RN^2} = \frac{1}{p^2} = a^4x'^2 + b^4y'^2 + c^4z'^2:$$

r being the length of that radius vector of the ray-surface which corresponds to the point R of the indicatrix.

5. *Given the co-ordinates $x'y'z'$ of R, to find the direction-cosines of the normal of the plane of polarisation of the corresponding ray Or.*

The plane of polarisation, being perpendicular to the normal RN (Fig. 5), is parallel to the tangent plane of the indicatrix at the point R; the equation of the tangent plane may be written in the form

$$pa^2x'x + pb^2y'y + pc^2z'z = p.$$

Hence the direction-cosines of the normal of the plane of polarisation are

$$pa^2x',\ pb^2y',\ pc^2z';$$

or $$\frac{a^2x'}{r},\ \frac{b^2y'}{r},\ \frac{c^2z'}{r};$$

where $r^2 = a^4x'^2 + b^4y'^2 + c^4z'^2$.

6. *Given the co-ordinates $x'y'z'$ of R, to find the direction-cosines of the corresponding ray Or.*

The direction-cosines of RN (Fig. 5) being $\frac{a^2x'}{r}, \frac{b^2y'}{r}, \frac{c^2z'}{r}$, and those of OR being $\frac{x'}{r'}, \frac{y'}{r'}, \frac{z'}{r'}$, where $r' = OR$, the direction-cosines $h\,k\,l$ of a line perpendicular to both RN and OR, and therefore to the plane RON and all lines therein, are given by the equations:—

$$hx' + ky' + lz' = 0$$
$$ha^2x' + kb^2y' + lc^2z' = 0:$$

hence

$$\frac{h}{y'z'(b^2 - c^2)} = \frac{k}{z'x'(c^2 - a^2)} = \frac{l}{x'y'(a^2 - b^2)}.$$

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If $\lambda\,\mu\,\nu$ be the direction-cosines of any line whatsoever in the same plane

$$\lambda h+\mu k+\nu l=0$$

$$\text{or } \lambda y'z'\,(b^2-c^2)+\mu z'x'\,(c^2-a^2)+\nu x'y'\,(a^2-b^2)=0.$$

Let the line $\lambda\,\mu\,\nu$ coincide with Or, in which case it is at right angles to RN, of which the direction-cosines are $\frac{a^2x'}{r}, \frac{b^2y'}{r}, \frac{c^2z'}{r}$; we thus have

$$\lambda a^2x'+\mu b^2y'+\nu c^2z'=0.$$

Determining the ratios $\lambda:\mu:\nu$ from the last two equations, we get

$$\frac{\lambda}{A}=\frac{\mu}{B}=\frac{\nu}{C}$$

where

$$\begin{aligned} A &= x'z'^2\,c^2(c^2-a^2) - x'y'^2\,b^2(a^2-b^2) = x'(r^2-a^2),\\ B &= y'x'^2\,a^2(a^2-b^2) - y'z'^2\,c^2(b^2-c^2) = y'(r^2-b^2),\\ C &= z'y'^2\,b^2\,(b^2-c^2) - z'x'^2\,a^2(c^2-a^2) = z'(r^2-c^2)\,; \end{aligned}$$

$$\text{or } \frac{\lambda}{x'(r^2-a^2)}=\frac{\mu}{y'(r^2-b^2)}=\frac{\nu}{z'(r^2-c^2)}$$

in which $r^2=a^4x'^2+b^4y'^2+c^4z'^2$, as before.

These equations determine the direction-cosines $\lambda\,\mu\,\nu$ of the ray Or corresponding to the point $x'y'z'$ or R.

7. The equation of the ray-surface.

The co-ordinates of r being $x\,y\,z$, we have $x=\lambda r$, $y=\mu r$, $z=\nu r$: $\lambda\,\mu\,\nu$ being the direction-cosines of the ray Or.

Hence, substituting these values in the last set of equations,

$$\frac{x}{\frac{r^2-a^2}{x'}}=\frac{y}{\frac{r^2-b^2}{y'}}=\frac{z}{\frac{r^2-c^2}{z'}}.$$

Each of these fractions is equal to

$$\frac{a^2x\frac{x}{r^2-a^2}+b^2y\frac{y}{r^2-b^2}+c^2z\frac{z}{r^2-c^2}}{a^2xx'+b^2yy'+c^2zz'}.$$

But the denominator of the last expression is zero; for by construction the line Or, of which the direction-cosines are $\frac{x}{r}, \frac{y}{r}, \frac{z}{r}$, is perpendicular to RN, of which the direction-cosines are $\frac{a^2x'}{r}, \frac{b^2y'}{r}, \frac{c^2z'}{r}$ (Art. 5).

Hence the numerator is also zero; for the fractions equivalent to the expression are never all of them indeterminate, and are never infinite.

$$\text{Thus } \frac{a^2x^2}{r^2-a^2}+\frac{b^2y^2}{r^2-b^2}+\frac{c^2z^2}{r^2-c^2}=0:$$

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this is the equation of the ray-surface, for it expresses a relation between the co-ordinates $x\,y\,z$ of any point r lying in it.

The equation may also be written in the form

$$\frac{a^2x^2}{r^2-a^2}+x^2+\frac{b^2y^2}{r^2-b^2}+y^2+\frac{c^2z^2}{r^2-c^2}+z^2=r^2,$$

or

$$\frac{x^2}{r^2-a^2}+\frac{y^2}{r^2-b^2}+\frac{z^2}{r^2-c^2}=1.$$

8. *Given $\lambda\,\mu\,\nu$, the direction-cosines of a line of transmission, to find r_1, r_2 the velocities of the corresponding rays Or_1 Or_2.*

Substituting the values $x=\lambda r$, $y=\mu r$, $z=\nu r$ in the equation of the ray-surface, we have

$$\frac{a^2\lambda^2}{r^2-a^2}+\frac{b^2\mu^2}{r^2-b^2}+\frac{c^2\nu^2}{r^2-c^2}=0;$$

and, multiplying out,

$$r^4\,(a^2\lambda^2+b^2\mu^2+c^2\nu^2)-r^2\{a^2(b^2+c^2)\,\lambda^2+b^2\,(c^2+a^2)\,\mu^2+c^2\,(a^2+b^2)\,\nu^2\}+a^2b^2c^2=0.$$

This being a quadratic equation in r^2, there are in general, for given values of $\lambda\ \mu\ \nu$, two solutions, say r_1^2 r_2^2, and thus two velocities of transmission in the given direction.

A geometrical solution is given in Art. 15.

The above equation may sometimes be conveniently written in the form

$$\frac{\lambda^2}{\frac{1}{r^2}-\frac{1}{a^2}}+\frac{\mu^2}{\frac{1}{r^2}-\frac{1}{b^2}}+\frac{\nu^2}{\frac{1}{r^2}-\frac{1}{c^2}}=0.$$

9. *Given $\lambda\ \mu\ \nu$, the direction-cosines of a line of transmission, to find the co-ordinates $x_1'\ y_1'\ z_1'$, $x_2'\ y_2'\ z_2'$ of the points $R_1\ R_2$ of the indicatrix which correspond to the rays Or_1 Or_2 respectively.*

Having found r_1^2 and r_2^2, as indicated in the last Article, the co-ordinates $x_1'\ y_1'\ z_1'$, $x_2'\ y_2'\ z_2'$ are given by the equations (Art. 6):—

$$\frac{x_1'}{\frac{\lambda}{r_1^2-a^2}}=\frac{y_1'}{\frac{\mu}{r_1^2-b^2}}=\frac{z_1'}{\frac{\nu}{r_1^2-c^2}}=L_1\ (\text{say}),$$

and

$$\frac{x_2'}{\frac{\lambda}{r_2^2-a^2}}=\frac{y_2'}{\frac{\mu}{r_2^2-b^2}}=\frac{z_2'}{\frac{\nu}{r_2^2-c^2}}=L_2\ (\text{say}):$$

remembering that

$$a^2x_1'^2+b^2y_1'^2+c^2z_1'^2=1,$$

and $$a^2x_2'^2+b^2y_2'^2+c^2z_2'^2=1,$$

since the points $R_1\ R_2$ are on the indicatrix.

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10. *The points $R_1 R_2$, corresponding to the rays Or_1 Or_2 transmissible along the line $\lambda\mu\nu$, are in a plane conjugate to that line.*

Since the normals of the indicatrix at $R_1 R_2$ are both perpendicular to the line $\lambda\ \mu\ \nu$ we have

$$\lambda a^2 x_1' + \mu b^2 y_1' + \nu c^2 z_1' = 0$$
$$\lambda a^2 x_2' + \mu b^2 y_2' + \nu c^2 z_2' = 0.$$

Hence the points $R_1 R_2$ are in the plane

$$\lambda a^2 x + \mu b^2 y + \nu c^2 z = 0.$$

This is the equation of a plane passing through the centre of the indicatrix and parallel to the planes which touch the indicatrix at either of the points where the line $\lambda\ \mu\ \nu$ intersects it.

It is also obvious geometrically that the tangent planes at $R_1 R_2$ are both of them parallel to Or, and that Or is therefore parallel to their line of intersection; Or is thus conjugate to the plane containing the points O, R_1, R_2.

And it is geometrically evident that at *all* points of the section made by the conjugate plane the tangent planes to the indicatrix are parallel to, and therefore their normals perpendicular to, the conjugate line $\lambda\ \mu\ \nu$: the points $R_1 R_2$ are those of the section for which the normals of the indicatrix are not only perpendicular to the line $\lambda\ \mu\ \nu$, but intersect it.

11. *Given the direction of transmission, to find the positions of the corresponding points $R_1 R_2$ in the conjugate plane.*

From the last Article, it follows that the tangent planes to the indicatrix at its intersection with the conjugate plane form a tangent cylinder, having its axis parallel to the direction of transmission. Let UKV be the curve of contact of the cylinder and indicatrix (Fig. 8): $R_1 R_2$ are somewhere on the curve UKV.

As a line is only perpendicular to its conjugate plane when it coincides with an axis of the indicatrix, Or, the axis of the cylinder, is in general oblique to UKV, the conjugate plane.

Let $U'K'V'$, $U''K''V''$ be sections of the cylinder by two planes perpendicular to its axis; they are in general ellipses: let $K''KK'$ be any line on the cylinder parallel to the axis, and $K''L''$, KL, $K'L'$, be the normals of the cylinder at the points K'', K, K', respectively; they are evidently parallel to each other.

But KL is also the normal of the indicatrix at K, for the cylinder and indicatrix are tangent to each other at that point: also $K'L'$ lies in the plane $U'K'V'$, since that plane is perpendicular to the axis of the cylinder: hence $K'L'$ is a normal of the ellipse $U'K'V'$ at the point K'.

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The line KL will thus only intersect the axis of the cylinder when $K'L'$ is an axis of the section $U'K'V'$.

Hence the points $R_1 R_2 \overline{R}_1 \overline{R}_2$ are the four positions of K, on the curve UKV, for which the normal of the indicatrix intersects the axis of the cylinder: and these four positions are projections, by lines parallel to the axis of the cylinder, of the extremities of the axes of its "base;" the base being taken as perpendicular to the axis of the cylinder.

In other words, the points $R_1 R_2$ and the normals R_1N_1 R_2N_2 lie in the *planes of symmetry of that tangent cylinder* of the indicatrix which has its axis in the common direction of transmission of the rays.

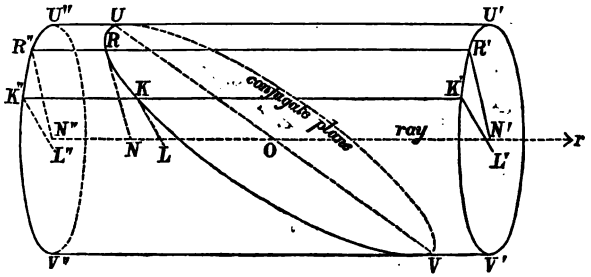

FIG. 8.

12. *The planes of polarisation of the two rays Or_1 Or_2 transmissible along the same line are perpendicular to each other.*

By the last Article, the normals R_1N_1 R_2N_2 are in the planes of symmetry of the tangent cylinder and at right angles to its axis: hence the planes of polarisation, to which the two lines are perpendicular, are themselves perpendicular to each other.

The following analytical proof is interesting by reason of the eliminations:—

The normals of the planes of polarisation being normals of the indicatrix at $R_1 R_2$, their direction-cosines are

$$\frac{a^2x_1'}{r_1}, \frac{b^2y_1'}{r_1}, \frac{c^2z_1'}{r_1},$$

$$\frac{a^2x_2'}{r_2}, \frac{b^2y_2'}{r_2}, \frac{c^2z_2'}{r_2}, \text{ respectively (Art. 5);}$$

hence, if ϕ be the angle between the planes of polarisation,

$$\cos\phi = \frac{1}{r_1 r_2}(a^4x_1'x_2' + b^4y_1'y_2' + c^4z_1'z_2').$$

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Substituting the values of $x_1'y_1'z_1'$, $x_2'y_2'z_2'$, from Article 9, we have

$$\cos\phi = \frac{L_1L_2}{r_1r_2}\left\{\frac{a^4\lambda^2}{(r_1^2-a^2)(r_2^2-a^2)}+\frac{b^4\mu^2}{(r_1^2-b^2)(r_2^2-b^2)}+\frac{c^4\nu^2}{(r_1^2-c^2)(r_2^2-c^2)}\right\}.$$

Now $r_1^2\, r_2^2$ being the roots of the equation given in Article 8, we have

$$r_1^2+r_2^2=\frac{a^2(b^2+c^2)\lambda^2+b^2(c^2+a^2)\mu^2+c^2(a^2+b^2)\nu^2}{a^2\lambda^2+b^2\mu^2+c^2\nu^2}$$

and
$$r_1^2r_2^2=\frac{a^2b^2c^2}{a^2\lambda^2+b^2\mu^2+c^2\nu^2}:$$

hence
$$(r_1^2-a^2)(r_2^2-a^2) = r_1^2r_2^2-a^2(r_1^2+r_2^2)+a^4$$
$$= -\frac{a^2\lambda^2}{b^2-c^2}\frac{(a^2-b^2)(b^2-c^2)(c^2-a^2)}{a^2\lambda^2+b^2\mu^2+c^2\nu^2}.$$

Similarly
$$(r_1^2-b^2)(r_2^2-b^2) = -\frac{b^2\mu^2}{c^2-a^2}\frac{(a^2-b^2)(b^2-c^2)(c^2-a^2)}{a^2\lambda^2+b^2\mu^2+c^2\nu^2},$$

and
$$(r_1^2-c^2)(r_2^2-c^2) = -\frac{c^2\nu^2}{a^2-b^2}\frac{(a^2-b^2)(b^2-c^2)(c^2-a^2)}{a^2\lambda^2+b^2\mu^2+c^2\nu^2}.$$

Hence
$$\frac{a^4\lambda^2}{(r_1^2-a^2)(r_2^2-a^2)}+\frac{b^4\mu^2}{(r_1^2-b^2)(r_2^2-b^2)}+\frac{c^4\nu^2}{(r_1^2-c^2)(r_2^2-c^2)}=0,$$

and ϕ is a right angle.

13. *If ρ be the point in which Or intersects the indicatrix, the lines $O\rho$ OR_1 OR_2 form a triad of conjugate diameters of the indicatrix.*

The axes of the basal section $U'K'V'$ (Fig. 8) of the tangent cylinder of the indicatrix being conjugate to each other, it follows, from the properties of parallel projection, that the projections of the axes on any section of the cylinder are conjugate diameters of the curve of section: hence the line $O\rho$ and the lines OR_1 OR_2 (which are the projections of the basal axes on the conjugate plane of Or), form a triad of conjugate diameters of the indicatrix, each being conjugate to the plane of the other two.

This may also be proved analytically, as follows:—

Substituting the values of $x_1'\, y_1'\, z_1'$, $x_2'\, y_2'\, z_2'$, given in Art. 9, we find that

$$a^2x_1'x_2'+b^2y_1'y_2'+c^2z_1'z_2'=$$
$$L_1L_2\left\{\frac{a^2\lambda^2}{(r_1^2-a^2)(r_2^2-a^2)}+\frac{b^2\mu^2}{(r_1^2-b^2)(r_2^2-b^2)}+\frac{c^2\nu^2}{(r_1^2-c^2)(r_2^2-c^2)}\right\}.$$

The quantity within the brackets is zero, as may be seen from the last Article, or more directly by subtraction of the equations

$$\frac{a^2\lambda^2}{r_1^2-a^2}+\frac{b^2\mu^2}{r_1^2-b^2}+\frac{c^2\nu^2}{r_1^2-c^2}=0$$
$$\frac{a^2\lambda^2}{r_2^2-a^2}+\frac{b^2\mu^2}{r_2^2-b^2}+\frac{c^2\nu^2}{r_2^2-c^2}=0.$$

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Hence $a^2x_1'x_2' + b^2y_1'y_2' + c^2z_1'z_2' = 0$; but this is the condition that the lines OR_1 OR_2 may be parallel to the tangent planes at R_2 and R_1 respectively: as those tangent planes are likewise both parallel to the line Or, the three lines form a triad of conjugate diameters.

Corollary. The normal of the indicatrix at the point R_1, though it intersects the line Or, only intersects the line OR_2 when N_1 coincides with O (Fig. 14); hence it follows that if OR_2 be a line of ray-transmission, R_1 is *not* one of the corresponding points on the indicatrix: in general the lines of the conjugate triad $O\rho$ OR_1 OR_2 are thus not interchangeable in character.

14. *Given r_1 r_2, the velocities of two rays which are transmitted in the same direction, to find λ μ ν the direction-cosines of the line of transmission.*

From Article **8**,

$$\frac{\lambda^2}{\frac{1}{r_1^2}-\frac{1}{a^2}} + \frac{\mu^2}{\frac{1}{r_1^2}-\frac{1}{b^2}} + \frac{\nu^2}{\frac{1}{r_1^2}-\frac{1}{c^2}} = 0,$$

$$\frac{\lambda^2}{\frac{1}{r_2^2}-\frac{1}{a^2}} + \frac{\mu^2}{\frac{1}{r_2^2}-\frac{1}{b^2}} + \frac{\nu^2}{\frac{1}{r_2^2}-\frac{1}{c^2}} = 0.$$

Determining the ratios $\lambda^2 : \mu^2 : \nu^2$ from these equations, we find that

$$\frac{\lambda^2}{\left(\frac{1}{b^2}-\frac{1}{c^2}\right)\left(\frac{1}{r_1^2}-\frac{1}{a^2}\right)\left(\frac{1}{r_2^2}-\frac{1}{a^2}\right)}$$

is equal to the two corresponding symmetrical fractions.

Each of the fractions is equal to the fraction of which the numerator is the sum of the three numerators, and the denominator the sum of the three denominators.

The sum of the numerators of the three fractions is unity: the sum of the denominators is

$$\frac{1}{r_1^2r_2^2}\left[\left(\frac{1}{b^2}-\frac{1}{c^2}\right)+\left(\frac{1}{c^2}-\frac{1}{a^2}\right)+\left(\frac{1}{a^2}-\frac{1}{b^2}\right)\right]$$

$$-\left(\frac{1}{r_1^2}+\frac{1}{r_2^2}\right)\left[\frac{1}{a^2}\left(\frac{1}{b^2}-\frac{1}{c^2}\right)+\frac{1}{b^2}\left(\frac{1}{c^2}-\frac{1}{a^2}\right)+\frac{1}{c^2}\left(\frac{1}{a^2}-\frac{1}{b^2}\right)\right]$$

$$+\frac{1}{a^4}\left(\frac{1}{b^2}-\frac{1}{c^2}\right)+\frac{1}{b^4}\left(\frac{1}{c^2}-\frac{1}{a^2}\right)+\frac{1}{c^4}\left(\frac{1}{a^2}-\frac{1}{b^2}\right).$$

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The coefficients of $\frac{1}{r_1^2 r_2^2}$ and $\frac{1}{r_1^2}+\frac{1}{r_2^2}$ vanish, and the remaining term may be transformed into

$$-\left(\frac{1}{a^2}-\frac{1}{b^2}\right)\left(\frac{1}{b^2}-\frac{1}{c^2}\right)\left(\frac{1}{c^2}-\frac{1}{a^2}\right).$$

Hence
$$\lambda^2=\frac{\left(\frac{1}{r_1^2}-\frac{1}{a^2}\right)\left(\frac{1}{r_2^2}-\frac{1}{a^2}\right)}{\left(\frac{1}{b^2}-\frac{1}{a^2}\right)\left(\frac{1}{c^2}-\frac{1}{a^2}\right)},$$

$$\mu^2=\frac{\left(\frac{1}{r_1^2}-\frac{1}{b^2}\right)\left(\frac{1}{r_2^2}-\frac{1}{b^2}\right)}{\left(\frac{1}{c^2}-\frac{1}{b^2}\right)\left(\frac{1}{a^2}-\frac{1}{b^2}\right)},$$

$$\nu^2=\frac{\left(\frac{1}{r_1^2}-\frac{1}{c^2}\right)\left(\frac{1}{r_2^2}-\frac{1}{c^2}\right)}{\left(\frac{1}{a^2}-\frac{1}{c^2}\right)\left(\frac{1}{b^2}-\frac{1}{c^2}\right)}.$$

15. *Given the direction of a line of transmission, to find the velocities of the corresponding rays.*

If RR' (Fig. 8) be parallel to the axis of the cylinder, and R' be the extremity of an axis of the base, it follows from Article **11** that R is a point on the indicatrix corresponding to a ray transmissible along the axis of the cylinder. The corresponding velocity being $\frac{1}{\overline{RN}}=\frac{1}{\overline{R'N'}}$, it is seen that the velocities of transmission are inversely proportional to the axes of the base of the cylinder. An analytical solution is given in Art. **8**.

16. The optic bi-radials (*secondary optic axes*).

From Article **15** it follows that if the two velocities of transmission in a given direction are equal, the corresponding tangent cylinder has a circular base. But at *every* point K' (Fig. 8) on the edge of the base of such a cylinder, the normal of the basal section and therefore of the cylinder, and consequently also the normal of the cylinder and therefore of the indicatrix at every corresponding point K of the section conjugate to the ray, intersect the axis of the cylinder perpendicularly, and have the same length intercepted between the surface and the axis: hence *every* point on the conjugate section corresponds to a ray transmissible with the same velocity along the axis of the cylinder: the normals of the indicatrix at these points, and therefore the planes of polarisation, may have any azimuth whatever.

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That in the plane AOC there are two directions, and only two, namely those of the lines Os_1 Os_2 (Fig. 7c), for which the two velocities of transmission are equal, has already been proved (Art. 3).

Along each of these lines Os_1 Os_2, rays can thus be transmitted having any azimuth of plane of polarisation whatever, and the velocity of transmission is b for all of them: in the case of calcite and analogous crystals, such properties only belong to that single direction which is termed the optic axis. By reason of this analogy, the directions Os_1 Os_2 have been likewise termed optic axes.

But not being perpendicular to the corresponding ray-fronts, they do not possess all the characters which belong to the optic axis of a uniaxal crystal: from another pair of directions, of which the optical characters are also such as in the case of a uniaxal crystal only belong to the optic axis, they have been distinguished as *Secondary Optic Axes;* and by Sir William Hamilton as *Lines of Single Ray-Velocity*.[1]

In the case of a biaxal crystal, it is experimentally determined that none of the so-called optic axes, primary or secondary, have directions which pass permanently through the same lines of crystalline particles; the lines of particles through which they pass differ with the colour of the light and the temperature of the crystal: hence the so-called optic axes have no material existence, and are in no proper sense of the word *axes of the crystal*.

Where precision of thought and language is necessary, the lines may appropriately be termed *the Optic Bi-radials*, for they are directions in which a line is doubly a radius vector of the ray-surface: the term *uni-radial* has already been assigned a distinct signification by Mac Cullagh.[2]

When the indicatrix is a spheroid at all temperatures of the crystal and for all colours of light, the bi-radial is found to be an axis of morphological and physical symmetry, and an axis of revolution of the ray-surface; it always passes through the same line of crystalline particles: such a line may be regarded as a true axis of the crystal.

17. *There cannot be more than one pair of optic bi-radials.*

It has already been proved that Os_1 Os_2 are the only directions for which the velocities of the rays transmissible along the same line, lying in a plane of symmetry of the indicatrix, are equal: it remains to prove that there are no other bi-radials in any direction whatever.

[1] *Trans. Roy. Irish Acad.*: 1837, vol. 17, p. 132.

[2] *Ibid.*: 1839, vol. 18, p. 40.

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From Article 8 it is seen that the velocity of transmission r is connected with the values of $\lambda\ \mu\ \nu$ by the equation

$$\frac{a^2\lambda^2}{r^2-a^2}+\frac{b^2\mu^2}{r^2-b^2}+\frac{c^2\nu^2}{r^2-c^2}=0;$$

whence

$$a^2\lambda^2(r^2-b^2)(r^2-c^2)+b^2\mu^2(r^2-c^2)(r^2-a^2)+c^2\nu^2(r^2-a^2)(r^2-b^2)=0.$$

Since $a\ b\ c$ are in descending order of magnitude, the expression on the left-hand side of the last equation is positive, and therefore cannot be zero, if r has any value greater than a or less than c: hence no velocity of transmitted ray can be greater than a or less than c.

Further, if μ is distinct from zero, the above expression is necessarily negative when $r=b$; hence it changes sign and passes through a zero value as r decreases from a to b, and again as r decreases from b to c. If μ is distinct from zero, the two values of r^2 which satisfy the above equation are thus unequal.

Hence the bi-radials can only lie in the plane AOC.

That in the plane AOC there are only two such lines may also be seen from the fact that for any direction lying in this plane one velocity of transmission is always b; when the two velocities are equal the second velocity must also be b: hence if S is a point on the curve $AC\overline{A}\overline{C}$ such that the perpendicular to the radius vector conjugate to OS is equal to OB, the points S correspond to directions Os of single ray-velocity: there are four such points lying at the extremities of two diameters.

The directions Os may also be readily found from the above general equation: for all rays lying in the plane AOC, μ is zero, and the general relation becomes

$$\frac{a^2\lambda^2}{r^2-a^2}+\frac{c^2\nu^2}{r^2-c^2}=0;$$

hence, the rays in this plane for which the two velocities of transmission are both equal to b are given by the equation

$$\frac{a^2\lambda^2}{b^2-a^2}+\frac{c^2\nu^2}{b^2-c^2}=0,$$

which is identical with the equation given in Article 3.

18. *Equation of the planes conjugate to the optic bi-radials.*

The equation of a plane conjugate to a line $\lambda\ \mu\ \nu$ is

$$a^2x\lambda+b^2y\mu+c^2z\nu=0.$$

For the bi-radials, $\mu=0$ and

$$\frac{a^2\lambda^2}{b^2-a^2}+\frac{c^2\nu^2}{b^2-c^2}=0.$$

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Hence their conjugate planes are given by the equation

$$\frac{x^2}{a^2(b^2-c^2)} = \frac{z^2}{a^2(a^2-b^2)}.$$

19. *The direction of a line Or being defined by its inclinations σ_1 σ_2 to the bi-radials Os_1 Os_2, to find the planes of polarisation of the two rays which can be transmitted along it.*

Let $[s_1]$, $[s_2]$, $[r]$ (Fig. 9) be the sections of the indicatrix which are conjugate to the lines Os_1, Os_2, Or respectively, and let D_1 D_2 be two adjacent points of intersection of $[r]$ with $[s_1]$ and $[s_2]$.

D_1 being common to the sections $[r]$ and $[s_1]$, the tangent plane of the indicatrix at D_1 is parallel to both Or and Os_1, and therefore to the plane Ors_1 containing them. Similarly the tangent plane of the indicatrix at D_2 is parallel to the plane Ors_2.

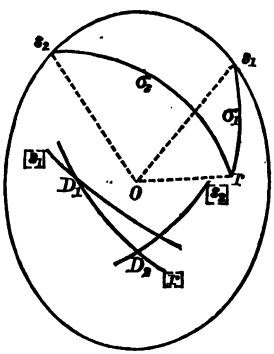

FIG. 9.

Also all planes tangent to the indicatrix at points on the sections $[s_1]$ and $[s_2]$ are equidistant from the origin (Art. **16**): hence the tangent planes of the indicatrix at D_1 and D_2 are equidistant from the line Or, and are therefore equally inclined to the planes of polarisation, for the latter are the planes of symmetry of the elliptic cylinder which touches the ellipsoid in the section $[r]$ (Art. **12.**).

Hence the planes of polarisation of the two rays transmissible in the direction Or are the internal and external bisectors of the angle between the planes Ors_1 Ors_2.

This is the first of the empirical laws of Biot (page 801).

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20. *The direction of a line Or being defined by its inclinations σ_1 σ_2 to the bi-radials Os_1 Os_2, to find the velocities of the two rays which can be transmitted along it.*

If r_1 r_2 be the respective velocities, it follows from the quadratic equation of Art. 8 that

$$\frac{1}{r_1^2}+\frac{1}{r_2^2}=\left(\frac{1}{b^2}+\frac{1}{c^2}\right)\lambda^2+\left(\frac{1}{c^2}+\frac{1}{a^2}\right)\mu^2+\left(\frac{1}{a^2}+\frac{1}{b^2}\right)\nu^2$$

$$\frac{1}{r_1^2 r_2^2}=\frac{\lambda^2}{b^2c^2}+\frac{\mu^2}{c^2a^2}+\frac{\nu^2}{a^2b^2}$$

where λ μ ν are the direction-cosines of Or.

It is necessary to express λ μ ν in terms of the angles σ_1 σ_2, and to substitute their values in the above expressions.

Let l 0 n, $\bar{l}$ 0 n be the direction-cosines of Os_1 Os_2 respectively, then

$$\cos\sigma_1 = l\lambda+n\nu, \qquad \cos\sigma_2 = -l\lambda+n\nu;$$

and $$2l\lambda = \cos\sigma_1 - \cos\sigma_2, \qquad 2n\nu = \cos\sigma_1 + \cos\sigma_2.$$

Also (from Art. 3)

$$l^2=\frac{\frac{1}{a^2}-\frac{1}{b^2}}{\frac{1}{a^2}-\frac{1}{c^2}}, \qquad n^2=\frac{\frac{1}{b^2}-\frac{1}{c^2}}{\frac{1}{a^2}-\frac{1}{c^2}}.$$

Substituting $1-\lambda^2-\nu^2$ for μ^2 in the expression for $\frac{1}{r_1^2}+\frac{1}{r_2^2}$, we get

$$\begin{aligned}\frac{1}{r_1^2}+\frac{1}{r_2^2} &= \frac{1}{a^2}+\frac{1}{c^2}-\lambda^2\left(\frac{1}{a^2}-\frac{1}{b^2}\right)+\nu^2\left(\frac{1}{b^2}-\frac{1}{c^2}\right)\\ &=\frac{1}{a^2}+\frac{1}{c^2}-\left(\frac{1}{a^2}-\frac{1}{c^2}\right)(l^2\lambda^2-n^2\nu^2)\\ &=\frac{1}{a^2}+\frac{1}{c^2}+\left(\frac{1}{a^2}-\frac{1}{c^2}\right)\cos\sigma_1\cos\sigma_2.\end{aligned}$$

Similarly,

$$\begin{aligned}\frac{1}{r_1^2r_2^2} &= \frac{1}{a^2c^2}-\frac{\lambda^2}{c^2}\left(\frac{1}{a^2}-\frac{1}{b^2}\right)+\frac{\nu^2}{a^2}\left(\frac{1}{b^2}-\frac{1}{c^2}\right)\\ &=\frac{1}{a^2c^2}-\left(\frac{1}{a^2}-\frac{1}{c^2}\right)\left(\frac{l^2\lambda^2}{c^2}-\frac{n^2\nu^2}{a^2}\right)\\ &=\frac{1}{a^2c^2}-\left(\frac{1}{a^2}-\frac{1}{c^2}\right)\left[\frac{(\cos\sigma_1-\cos\sigma_2)^2}{4c^2}-\frac{(\cos\sigma_1+\cos\sigma_2)^2}{4a^2}\right]\end{aligned}$$

and

$$\frac{4}{r_1^2r_2^2}=\frac{4}{a^2c^2}+\left(\frac{1}{a^2}-\frac{1}{c^2}\right)^2(\cos^2\sigma_1+\cos^2\sigma_2)+2\left(\frac{1}{a^2}-\frac{1}{c^2}\right)\cos\sigma_1\cos\sigma_2.$$

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Hence

$$\left(\frac{1}{r_1^2}-\frac{1}{r_2^2}\right)^2=\left(\frac{1}{r_1^2}+\frac{1}{r_2^2}\right)^2-\frac{4}{r_1^2r_2^2}$$

$$=\left(\frac{1}{a^2}-\frac{1}{c^2}\right)^2\sin^2\sigma_1\sin^2\sigma_2,$$

$$\text{or } \frac{1}{r_1^2}-\frac{1}{r_2^2}=\pm\left(\frac{1}{a^2}-\frac{1}{c^2}\right)\sin\sigma_1\sin\sigma_2.$$

If r_1 be the larger velocity, we thus have

$$\frac{1}{r_1^2}-\frac{1}{r_2^2}=\left(\frac{1}{a^2}-\frac{1}{c^2}\right)\sin\sigma_1\sin\sigma_2.$$

This is the second of the empirical laws of Biot (page 301).

From the above we find that

$$\frac{2}{r_1^2}=\frac{1}{a^2}+\frac{1}{c^2}+\left(\frac{1}{a^2}-\frac{1}{c^2}\right)\cos(\sigma_1-\sigma_2)$$

$$\frac{2}{r_2^2}=\frac{1}{a^2}+\frac{1}{c^2}+\left(\frac{1}{a^2}-\frac{1}{c^2}\right)\cos(\sigma_1+\sigma_2):$$

whence

$$\frac{1}{r_1^2}=\frac{1}{a^2}\cos^2\frac{\sigma_1-\sigma_2}{2}+\frac{1}{c^2}\sin^2\frac{\sigma_1-\sigma_2}{2}$$

$$\frac{1}{r_2^2}=\frac{1}{a^2}\cos^2\frac{\sigma_1+\sigma_2}{2}+\frac{1}{c^2}\sin^2\frac{\sigma_1+\sigma_2}{2}.$$

21. *The ray-front corresponding to the ray Or is perpendicular to the transverse plane RNOr, and intersects that plane in a line parallel to OR.*

Geometrical Proof.

(*a.*) As usual, let R (Fig. 10) be the point of the indicatrix corresponding to the ray Or, and RN be the normal of the indicatrix at R: and let $RDEN$ be a plane perpendicular to the plane $RNOr$; it will intersect the indicatrix in an ellipse. Let D be a point on this ellipse distant from R by an arc which is a small quantity of the first order: to this order of small quantities the normal of the ellipse at D is the normal of the indicatrix at that point: if OE be drawn to intersect DE perpendicularly, the line EN is, to the first order of small quantities, perpendicular to the plane $RNOr$ and parallel to DR, and DE is equal to RN. Hence, if Od be the ray corresponding to the point D of the indicatrix, the plane Ord is perpendicular to the plane $RNOr$, and $Od=\frac{1}{DE}$ by construction $=\frac{1}{RN}$ $=Or$. Hence the line rd is also perpendicular to the plane $RNOr$.

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But R and D being adjacent points on the indicatrix, r and d are adjacent points on the ray-surface, and the line rd is thus tangent to the ray-surface at r.

The tangent plane to the ray-surface at r is the plane of the ray-front corresponding to the ray Or: it must pass through all lines tangent to the ray-surface at r, and thus through the line rd, and be perpendicular therefore to the plane $RNOr$.

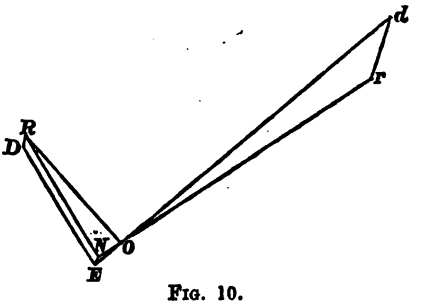

FIG. 10.

(*b.*) The plane $RNOr$ (Fig. 11) also will intersect the indicatrix in an ellipse: let G be a point on this ellipse distant from R by an arc which is a small quantity of the first order: to this order of small quantities GH, the normal of the ellipse at G, is also the normal of the indicatrix at that point. Hence if gOH be perpendicular to GH and $Og=\frac{1}{GH}$, Og is the direction of the ray corresponding to the point G, and g is a point on the ray-surface: in the same way as before it follows that rg is a tangent line of the ray-surface, and is thus the intersection of the tangent plane at r with the plane $RNOr$.

Let Or Og intersect the ellipse in the points R' G' respectively: then OR' and OG' are respectively conjugate to OR and OG, being perpendicular to RN and GH, and therefore parallel to the tangents at R and G: the area of a parallelogram of which the adjacent sides are conjugate radii vectores is constant; hence

$$RN \cdot OR' = GH \cdot OG'.$$

Also, by construction,

$$RN=\frac{1}{Or},\quad GH=\frac{1}{Og};$$

hence

$$Or : OR' = Og : OG',$$

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and the line rg is therefore parallel to the tangent of the ellipse at R', and consequently to the line OR which is conjugate to OR'.

Hence the ray-front corresponding to the ray Or intersects the transverse plane $RNOr$ perpendicularly in a line parallel to OR.

The diametral line Of, perpendicular to OR and lying in the plane $RNOr$, is therefore normal to the ray-front corresponding to the ray Or (Fig. 12).

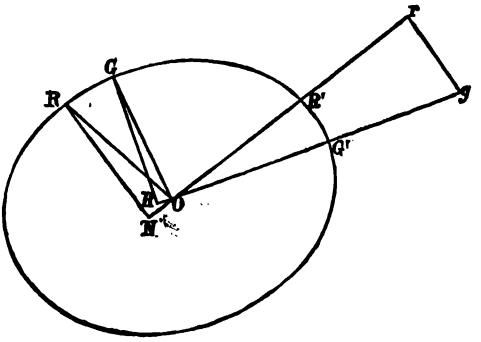

FIG. 11.

Analytical Proof.

The following is interesting to the mathematical student, by reason of the eliminations:—

From Article 7 we have

$$\frac{x}{\frac{r^2-a^2}{x'}} = \frac{y}{\frac{r^2-b^2}{y'}} = \frac{z}{\frac{r^2-c^2}{z'}} = \frac{1}{A} \text{ (say)};$$

hence $$x' = \frac{Ax}{r^2-a^2},\ y' = \frac{Ay}{r^2-b^2},\ z' = \frac{Az}{r^2-c^2}. \qquad (1).$$

Remembering that

$$\frac{x^2}{r^2-a^2} + \frac{y^2}{r^2-b^2} + \frac{z^2}{r^2-c^2} = 1 \text{ (Art. 7)},$$

we have $$xx'+yy'+zz' = A. \qquad (2).$$

Also $$a^2xx'+b^2yy'+c^2zz' = 0 \text{ (Art. 7)}. \qquad (3).$$

It is thus required to determine the tangent plane at a point $x\,y\,z$ of the ray-surface in terms of the co-ordinates $x'y'z'$, which are connected by the above equations and also by the relation

$$a^2x'^2+b^2y'^2+c^2z'^2 = 1. \qquad (4).$$

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Forming the differential of each of the equations (1), we have

$$\left.\begin{aligned}(r^2-a^2)\delta x'+2rx'\delta r &= A\delta x+x\delta A\\ (r^2-b^2)\delta y'+2ry'\delta r &= A\delta y+y\delta A\\ (r^2-c^2)\delta z'+2rz'\delta r &= A\delta z+z\delta A\end{aligned}\right\} \qquad (5).$$

Multiply these equations by a^2x' b^2y' c^2z' respectively and add: the quantity δA is thus eliminated, for its coefficient $a^2xx'+b^2yy'+c^2zz'$ vanishes by relation (3); we then have

$$(r^2-a^2)a^2x'\delta x'+(r^2-b^2)b^2y'\delta y'+(r^2-c^2)c^2z'\delta z'+2r\delta r = A\,(a^2x'\delta x+b^2y'\delta y+c^2z'\delta z).$$

Remembering that $a^2x'\delta x'+b^2y'\delta y'+c^2z'\delta z'=0$, owing to relation (4), we have

$$-(a^4x'\delta x'+b^4y'\delta y'+c^4z'\delta z')+2r\delta r = A(a^2x'\delta x+b^2y'\delta y+c^2z'\delta z).$$

But by Article 4

$$a^4x'^2+\quad b^4y'^2+\quad c^4z'^2=r^2;$$

whence

$$a^4x'\delta x'+b^4y'\delta y'+c^4z'\delta z'=r\delta r.$$

Substituting this value in the preceding equation, we have

$$r\delta r = A(a^2x'\delta x+b^2y'\delta y+c^2z'\delta z)$$

or

$$(x-Aa^2x')\delta x+(y-Ab^2y')\delta y+(z-Ac^2z')\delta z=0.$$

If $l\ m\ n$ be the direction-cosines of Of, the perpendicular to the tangent plane of the ray-surface at $x\ y\ z$, we must have

$$l\delta x+m\delta y+n\delta z=0, \text{ whence}$$

$$\frac{l}{x-Aa^2x'}=\frac{m}{y-Ab^2y'}=\frac{n}{z-Ac^2z'}: \qquad (6).$$

(*a*.) Each of these quantities is equal to

$$\frac{lx'+my'+nz'}{xx'-Aa^2x'^2+yy'-Ab^2y'^2+zz'-Ac^2z'^2}$$

or

$$\frac{lx'+my'+zz'}{xx'+yy'+zz'-A}.$$

The denominator of this expression is zero, by relation (2); hence the numerator $lx'+my'+nz'$ is also zero, for the three equivalent fractions are never all of them indeterminate, and are none of them infinite.

From the relation $$lx'+my'+nz'=0, \qquad (7).$$

it follows that Of is perpendicular to OR.

(*b*.) Also, multiplying both numerator and denominator of each of the fractions (6) by $y'z'(b^2-c^2)$, $z'x'(c^2-a^2)$, $x'y'(a^2-b^2)$ respectively, we find that each of them is equal to

$$\frac{ly'z'(b^2-c^2)+mz'x'(c^2-a^2)+nx'y'(a^2-b^2)}{y'z'(b^2-c^2)(x-Aa^2x')+z'x'(c^2-a^2)(y-Ab^2y')+x'y'(a^2-b^2)(z-Ac^2z')}.$$

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On expanding the denominator, it will be found that the terms involving A mutually destroy each other, owing to the identity

$$a^2(b^2-c^2)+b^2(c^2-a^2)+c^2(a^2-b^2)=0:$$

the denominator thus reduces to

$$xy'z'(b^2-c^2)+yz'x'(c^2-a^2)+zx'y'(a^2-b^2); \text{ or}$$

$$\frac{x'y'z'}{A}\left\{(r^2-a^2)(b^2-c^2)+(r^2-b^2)(c^2-a^2)+(r^2-c^2)(a^2-b^2)\right\}$$

owing to the equations (1).

When multiplied out, this term is likewise found to be zero.

Hence the numerator of the above expression is also zero, and we have he relation

$$ly'z'(b^2-c^2)+mz'x'(c^2-a^2)+nx'y'(a^2-b^2)=0. \quad (8).$$

But this is the condition (Art. 6) that the line Of may lie in the plane RON: hence the front-normal Of lies in the plane $RNOr$ and is perpendicular to OR.

Corollary 1. The inclination of a ray Or to its front-normal Of is the same as the inclination of the normal RN to the radius vector RO at the corresponding point R of the indicatrix (Fig. 12).

Corollary 2. If a ray coincides with the central normal to its ray-front, its direction is perpendicular to an axis of the indicatrix.

Corollary 3. If the ray Or lies in one of the symmetral planes of the indicatrix, the intersection of the corresponding ray-front with the symmetral plane is parallel to the line OR, which is conjugate to the line Or. But if P is any point on an ellipse and Q $\overline{Q}$ are the extremities of a diameter, the lines PQ $P\overline{Q}$ are parallel to a pair of conjugate diameters. Hence, if P Q $\overline{Q}$ lie in a symmetral plane of the indicatrix, and PQ represents the direction of a ray, the corresponding ray-front is a plane perpendicular to the symmetral plane, and intersects the latter in a line parallel to $P\overline{Q}$.

22. *For the ray Or, the plane of polarisation is perpendicular to the plane containing Or and Of the normal of the corresponding ray-front.*

This follows at once from the last Article, for RN, the normal of the plane of polarisation of the ray, lies in the plane $RNOr$ which has been shown to contain the line Ot.

In other words, the plane Orf is the tranverse plane for the ray Or.

23. *For the ray Or, corresponding to the point R, the resolved velocity along the normal to the ray-front is measured by the inverse of OR.*

If Of (Fig. 12) be perpendicular to OR and in the plane $RNOr$, and

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the angle rfO be a right angle, then, by Article **21**, f is the foot of the perpendicular drawn from O to the tangent plane of the ray-surface at r, and Of is the resolved velocity of the ray Or along the normal to the corresponding front.

But Or Of are by construction perpendicular respectively to RN and RO: hence the triangles rfO ONR are similar and $\frac{RN}{OR}=\frac{Of}{Or}$.

Also, by construction, $RN=\frac{1}{Or}$; hence $Of=\frac{1}{OR}$.

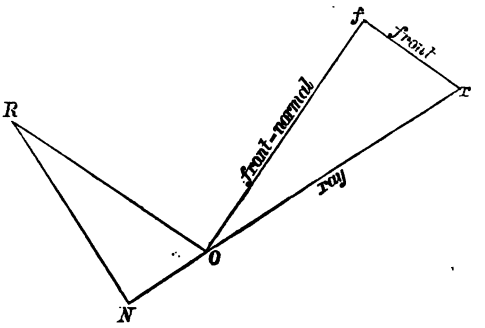

FIG. 12.

24. *The line OR is always a normal of the curve in which the indicatrix is intersected by a central plane parallel to that ray-front which corresponds to the ray Or: in the general case, OR is an axis of the curve.*

RN (Fig. 12) being the normal of the indicatrix at R, any line perpendicular to RN and to the plane $RNOr$ is tangent both to the indicatrix, and to the section of the indicatrix made by any plane which is perpendicular to the plane $RNOr$ at the point R; it is thus tangent to the particular section made by that plane of the series which passes through O. Of this section OR is a central radius vector: hence the tangent at R to the section is at right angles to a central radius vector.

The section being in general an ellipse, R is in such case the extremity of an axis of the section.

Hence it is seen that the ray-surface is the envelope of planes which are distant from a parallel central section of the indicatrix by the inverse lengths of the semi-axes of the latter curve: which is Fresnel's geometrical construction of the surface.

Conversely,

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25. *If OR is a central normal (and therefore in general an axis) of the curve in which the indicatrix is intersected by a plane parallel to a given direction of ray-front, the plane through OR normal to the direction of the ray-front contains the ray Or, which corresponds to the point R, and also the line RN, which is the normal of the plane of polarisation of the ray.*

The radius vector OR (Fig. 12) being a central normal of the curve of intersection, a line perpendicular to OR and lying in the plane parallel to the ray-front, is a tangent to the curve of intersection at R: hence RN the normal of the indicatrix at R must lie somewhere or other in the plane ROf perpendicular to this line.

And the ray Or must lie in the same plane.

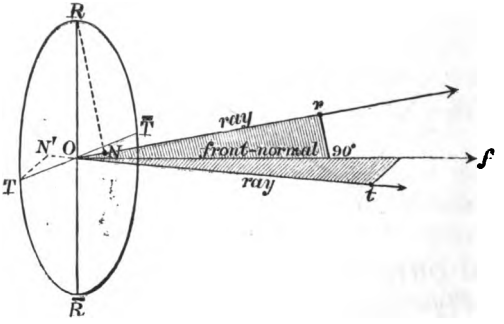

FIG. 13.

26. The two rays corresponding to a given direction of front-normal.

Hence if only the *direction of a ray-front* be given, there are in general two corresponding *positions* of the ray-front, or, in other words, of tangent planes to the ray-surface: and for each there is a corresponding ray (Fig. 13). The rays lie each of them in a plane containing the central normal Of and one of the axes OR OT of the section of the indicatrix by a plane parallel to the ray-front; they are thus in two perpendicular planes which intersect in the line Of: the corresponding velocities resolved along the given front-normal are measured by $\frac{1}{OR}$ and $\frac{1}{OT}$ respectively: the normal of the plane of polarisation is parallel to RN for the ray Or, and to TN' for the ray Ot. The directions of vibration at points of the respective rays, ac-

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cording to the latest version of the elastic theory, are thus indicated by the shading in Figure 13.

It may be remarked that the planes of polarisation of the rays Or Ot, though perpendicular to the normals RN TN', are not perpendicular to each other; for it is the lines RO TO, not the lines RN TN', which are at right angles: it is easily seen that the cosine of the angle between the planes is equal to $\sin fOr \sin fOt$. Hence only the transverse planes, not the planes of polarisation of the two rays, are perpendicular to each other.

27. The two front-normals corresponding to a given direction of ray.

Similarly, if only the *direction of a ray* be given, there are in general two corresponding *positions and directions* of the ray-front, and two corresponding rays (Fig. 14). The rays lie each of them in a plane

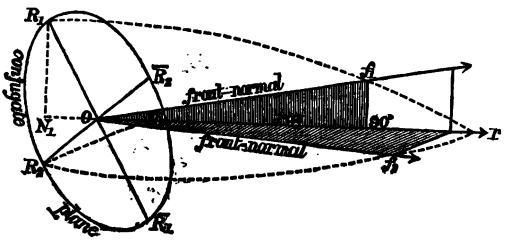

FIG. 14.

containing the ray-direction and one of the lines OR_1 OR_2: they are thus in two perpendicular planes which intersect in the line Or: the corresponding velocities are measured by $\frac{1}{R_1N_1}$ $\frac{1}{R_2N_2}$, respectively: the normal of the plane of polarisation is parallel to R_1N_1 for the ray Or_1, and to R_2N_2 for the ray Or_2. The directions of vibration at points of the respective rays, according to the latest version of the elastic theory, are thus indicated by the shading in Figure 14.

28. *Given the co-ordinates $x'y'z'$ of R, to find θ, the angle between the corresponding ray Or and its front-normal Of.*

Or Of being perpendicular to RN RO respectively (Fig. 12),

$$\cos\theta = \cos rOf = \cos NRO = \frac{RN}{RO} = \frac{1}{rr'}:$$

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hence $\tan^2\theta = r^2r'^2 - 1$

$$= (a^4x'^2 + b^4y'^2 + c^4z'^2)(x'^2 + y'^2 + z'^2) - (a^2x'^2 + b^2y'^2 + c^2z'^2)^2$$
$$= (a^2 - b^2)^2x'^2y'^2 + (b^2 - c^2)^2y'^2z'^2 + (c^2 - a^2)^2z'^2x'^2.$$

29. *Given the direction-cosines $\lambda\ \mu\ \nu$ of a line of transmission, to find θ, the angle between the corresponding ray Or and its front-normal Of.*

Find $r_1^2\ r_2^2$ (Art. 8), and then $x_1'y_1'z_1'\ x_2'y_2'z_2'$, the co-ordinates of the points R_1R_2 (Art. 9); also $r_1'^2 = x_1'^2 + y_1'^2 + z_1'^2$ and $r_2'^2 = x_2'^2 + y_2'^2 + z_2'^2$; finally we have $\sec\theta_1 = r_1r_1'$; $\sec\theta_2 = r_2r_2'$.

30. *If a ray lies in a given axial plane of the indicatrix, to find the direction for which the inclination θ to the front-normal is a maximum.*

First proof.

Let the given axial plane be AOC. Each direction of transmission lying in this plane corresponds to two points R_1R_2 on the indicatrix: one of these R_2 always coincides with B, and the corresponding ray coincides with its front-normal; the other R_1 is in the plane AOC, and the corresponding ray coincides with its front-normal only when R_1 is at $A\bar{A}\ C$ or $\bar{C}$.

If $x'\,0\,z'$ be the co-ordinates of R_1, $\tan\theta = (c^2 - a^2)\,z'x'$ (Art. 28).

Hence, writing $c^2z'^2 = 1 - a^2x'^2$, we have

$$\tan^2\theta = \left(\frac{c}{a} - \frac{a}{c}\right)^2 (1 - a^2x'^2)\,a^2x'^2 = \left(\frac{c}{a} - \frac{a}{c}\right)^2 \left\{\tfrac{1}{4} - (a^2x'^2 - \tfrac{1}{2})^2\right\}.$$

For a maximum value of θ, $a^2x'^2 = \frac{1}{2} = c^2z'^2$.

Or being parallel to the tangent of the indicatrix at R_1,

$$\tan rOA = -\frac{a^2x'}{c^2z'} = \pm\frac{a}{c}$$

or Or is parallel to AC or $\bar{A}C$, when the inclination to the front-normal is a maximum.

Second proof.

From Article 21, Corollary 3, if P is a point on the indicatrix lying in the symmetral plane AOC, and PA represents the direction of a ray belonging to the elliptic section, the corresponding ray-front is perpendicular to the plane AOC and intersects it in a line parallel to $P\bar{A}$; hence the angle $AP\bar{A}$ is the angle of inclination of the ray to its front: the interior angle is a minimum when P coincides with C or $\bar{C}$.

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31. *If a ray lies in a given axial plane of the indicatrix, to find the maximum inclination of the ray to its front-normal.*

First proof.

Taking AOC for the given axial plane, as in the preceding Article, we have, when $a^2x'^2=\frac{1}{2}$,

$$\tan\theta=\pm\tfrac{1}{2}\left(\frac{c}{a}-\frac{a}{c}\right),$$

and $\cot\theta=\tan 2\,ACO$, or $\theta=\frac{\pi}{2}-2\,ACO$.

Hence the maximum or minimum angle which a ray lying in the axial plane AOC can make with its front is given by the angle $AC\overline{A}$.

Second proof.

This result is also manifest from the fact that when the ray Or is parallel to $\bar{A}C$, the conjugate diameter OR_1, and therefore also the ray-front, is parallel to CA; as in the second proof given in Art. **30**.

32. *Given the co-ordinates $x'y'z'$ of R, to find the direction-cosines $l\,m\,n$ of the normal Of to the corresponding ray-front.*

For any line $l\,m\,n$ in the plane $RNOr$, as already proved in Article **6**, we have the equation

$$ly'z'(b^2-c^2)+mz'x'(c^2-a^2)+nx'y'(a^2-b^2)=0.$$

If the line $l\,m\,n$ is likewise perpendicular to OR, of which the direction-cosines are $\frac{x'}{r'}, \frac{y'}{r'}\frac{z'}{r'}$, we have also

$$lx'+my'+nz'=0.$$

From these equations the ratios $l:m:n$ are found to be:—

$$\frac{l}{D}=\frac{m}{E}=\frac{n}{F}$$

where

$$D=x'z'^2(c^2-a^2)-x'y'^2(a^2-b^2)=x'(1-a^2r'^2),$$
$$E=y'x'^2(a^2-b^2)-y'z'^2(b^2-c^2)=y'(1-b^2r'^2),$$
$$F=z'y'^2(b^2-c^2)-z'x'^2(c^2-a^2)=z'(1-c^2r'^2);$$

whence

$$\frac{l}{x'(1-a^2r'^2)}=\frac{m}{y'(1-b^2r'^2)}=\frac{n}{z'(1-c^2r'^2)},$$

where $r'^2=OR^2=x'^2+y'^2+z'^2$.

These equations determine the direction-cosines $l\,m\,n$ of the normal Of of the ray-front corresponding to the point $x'y'z'$ or R.

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33. *Given the direction-cosines $l\,m\,n$ of the front-normal Of, to find $f_1\,f_2$ the respective velocities of the two corresponding ray-fronts resolved normally to them.*

In Article **23** it was shown that the velocity of the ray-front of the ray Or resolved normally to the front is $\frac{1}{OR}$: denoting the resolved velocity by f and substituting $f=\frac{1}{OR}=\frac{1}{r'}$ in the equations of the last Article, we have

$$\frac{l}{f^2-a^2}=\frac{m}{f^2-b^2}=\frac{n}{f^2-c^2}.$$

Each of these fractions is equal to

$$\frac{l\frac{l}{f^2-a^2}+m\frac{m}{f^2-b^2}+n\frac{n}{f^2-c^2}}{lx'+my'+nz'}.$$

But the denominator of the last expression has been proved to be zero (Art. **32**); hence the numerator is also zero, for the fractions equivalent to the expression are never all of them indeterminate and are never infinite; we thus have

$$\frac{l^2}{f^2-a^2}+\frac{m^2}{f^2-b^2}+\frac{n^2}{f^2-c^2}=0.$$

This is a quadratic equation in f^2, and its two roots $f_1^2\,f_2^2$ are the resolved velocities required.

Multiplied out it takes the form

$$f^4-f^2\{(b^2+c^2)l^2+(c^2+a^2)m^2+(a^2+b^2)n^2\}+b^2c^2l^2+c^2a^2m^2+a^2b^2n^2=0.$$

34. *Given $f_1\,f_2$, the velocities of normal-transmission of two ray-fronts having a common direction of normal Of_1f_2, to find $l\,m\,n$ the direction-cosines of the latter.*

From Art. **33**,

$$\frac{l^2}{f_1^2-a^2}+\frac{m^2}{f_1^2-b^2}+\frac{n^2}{f_1^2-c^2}=0$$

$$\frac{l^2}{f_2^2-a^2}+\frac{m^2}{f_2^2-b^2}+\frac{n^2}{f_2^2-c^2}=0.$$

Determining the ratios $l^2:m^2:n^2$ from these equations, we find that

$$\frac{l^2}{(b^2-c^2)(f_1^2-a^2)(f_2^2-a^2)}=\frac{m^2}{(c^2-a^2)(f_1^2-b^2)(f_2^2-b^2)}=\frac{n^2}{(a^2-b^2)(f_1^2-c^2)(f_2^2-c^2)}.$$

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The sum of the numerators of the fractions is unity: the sum of the denominators is

$$f_1^2 f_2^2 [(b^2-c^2)+(c^2-a^2)+(a^2-b^2)]$$
$$-(f_1^2+f_2^2)[a^2(b^2-c^2)+b^2(c^2-a^2)+c^2(a^2-b^2)]$$
$$+a^4(b^2-c^2)+b^4(c^2-a^2)+c^4(a^2-b^2).$$

The coefficients of $f_1^2 f_2^2$ and $f_1^2+f_2^2$ vanish, and the remaining term may be transformed into

$$-(a^2-b^2)(b^2-c^2)(c^2-a^2).$$

Hence
$$l^2=\frac{(f_1^2-a^2)(f_2^2-a^2)}{(b^2-a^2)(c^2-a^2)},$$
$$m^2=\frac{(f_1^2-b^2)(f_2^2-b^2)}{(c^2-b^2)(a^2-b^2)},$$
$$n^2=\frac{(f_1^2-c^2)(f_2^2-c^2)}{(a^2-c^2)(b^2-c^2)}.$$

35. *Given the direction-cosines $l\ m\ n$ of the normals Of_1 Of_2 of two ray-fronts having the same direction, to find the co-ordinates $x_1'y_1'z_1'$ $x_2'y_2'z_2'$ of the corresponding points R T on the indicatrix.*

The values $f_1^2 f_2^2$ having been found by the equation of Article **33**, the co-ordinates x_1' y_1' z_1', x_2' y_2' z_2' of the points R and T respectively are determined by the following equations, also from Art. **33**:—

$$\frac{x_1'}{l\sqrt{f_1^2-a^2}}=\frac{y_1'}{m\sqrt{f_1^2-b^2}}=\frac{z_1'}{n\sqrt{f_1^2-c^2}};$$
$$\frac{x_2'}{l\sqrt{f_2^2-a^2}}=\frac{y_2'}{m\sqrt{f_2^2-b^2}}=\frac{z_2'}{n\sqrt{f_2^2-c^2}}:$$

remembering, also, that the co-ordinates of each point must satisfy the equation of the indicatrix.

It will be observed that the above equations are identical in form with those given in Art. **9**: in the one case the direction-cosines and velocities are those belonging to the rays, and in the other case are those belonging to the front-normals.

36. *Given $f_1 f_2$, the velocities of normal-transmission of two ray-fronts having a common direction of normal $Of_1 f_2$, to find the co-ordinates $x_1'y_1'z_1'$ $x_2'y_2'z_2'$ of the corresponding points R T on the indicatrix.*

From Art. **35**

$$\frac{x_1'}{l\sqrt{f_1^2-a^2}}=\frac{y_1'}{m\sqrt{f_1^2-b^2}}=\frac{z_1'}{n\sqrt{f_1^2-c^2}}=\frac{1}{A}\text{ (say)},$$

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The square of each of these fractions is equal to

$$\frac{x_1'^2+y_1'^2+z_1'^2}{\frac{l^2}{(f_1^2-a^2)^2}+\frac{m^2}{(f_1^2-b^2)^2}+\frac{n^2}{(f_1^2-c^2)^2}}.$$

Hence, remembering that $x_1'^2+y_1'^2+z_1'^2=OR^2=\frac{1}{f_1^2}$, we find on substituting the values of $l^2\ m^2\ n^2$ given in Art. **34**

$$-\frac{A^2}{f_1^2}=\Sigma\frac{f_2^2-a^2}{(c^2-a^2)(a^2-b^2)(f_1^2-a^2)}$$

$$\text{or}\quad \frac{\Sigma\{(b^2-c^2)(f_1^2-b^2)(f_1^2-c^2)(f_2^2-a^2)\}}{(a^2-b^2)(b^2-c^2)(c^2-a^2)(f_1^2-a^2)(f_1^2-b^2)(f_1^2-c^2)}$$

On expansion of the numerator it will be seen that the terms involving $f_1^4 f_2^2$ $f_1^2 f_2^2$ $f_1^4\ a^2b^2c^2$ all vanish, and that the coefficients of f_1^2 and f_2^2 are equal but of opposite sign: the numerator then takes the form

$$(f_1^2-f_2^2)(a^2-b^2)(b^2-c^2)(c^2-a^2)$$

$$\text{Hence}\quad A^2=-\frac{f_1^2(f_1^2-f_2^2)}{(f_1^2-a^2)(f_1^2-b^2)(f_1^2-c^2)},$$

$$\text{and}\quad x_1'^2=\frac{l^2}{A^2(f_1^2-a^2)^2}=\frac{(f_2^2-a^2)(f_1^2-b^2)(f_1^2-c^2)}{f_1^2(f_1^2-f_2^2)(c^2-a^2)(a^2-b^2)}.$$

Corresponding symmetrical expressions give the values of $y_1'^2z_1'^2\ x_2'^2y_2'^2z_2'^2$.

The above relation, with many others of this Section, was first given by Sylvester,[1] starting from the vibrational inferences of Fresnel.

37. *Given the direction-cosines $l\,m\,n$ of a front-normal Of, to find those of the corresponding rays Or Ot.*

Find the co-ordinates of R and T by the method of Art. **35**, and then the direction-cosines of the rays Or Ot by means of the equations in Article **6**.

38. *Given the direction-cosines of a ray Or, to find those of the corresponding front-normals.*

Find the co-ordinates of R_1 and R_2 (Art. **9**), and then the direction-cosines of the corresponding front-normals by Article **32**.

39. *The front-normal surface, or pedal of the ray-surface.*

It was shown in Art. **33** that if f be the velocity of transmission of a ray-front resolved along its normal Of, of which the direction-cosines are $l\,m\,n$,

$$\frac{l^2}{f^2-a^2}+\frac{m^2}{f^2-b^2}+\frac{n^2}{f^2-c^2}=0.$$

[1] *Philos. Magazine*, ser. 3: 1837, vol. 11, pp. 461, 537; 1838, vol. 12, pp. 73, 841.

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Hence, if $x\,y\,z$ be the co-ordinates of f, and the length of Of be denoted by r, we have

$$r = f:\ x = lr,\ y = mr,\ z = nr.$$

Substituting in the above equation, we get

$$\frac{x^2}{r^2 - a^2} + \frac{y^2}{r^2 - b^2} + \frac{z^2}{r^2 - c^2} = 0.$$

This is the equation of the locus of the points f, or of the pedal o the ray-surface: the velocity of normal propagation of a ray-front along any radius vector of the surface is measured by the length of the radius vector.

40. *The polar reciprocal of the ray-surface belongs to the same family surface of wave-slowness or index-surface.*

The radius of a concentric reciprocating sphere being taken as unity, the pole $\xi\,\eta\,\zeta$ which corresponds to the ray-front will lie in the front-normal Of at a distance $\frac{1}{Of}$ from the origin.

Hence if $x\,y\,z\,r$ refer to the point f, and $\xi\,\eta\,\zeta\,\rho$ to the pole of the ray-front, we have

$$\frac{x}{r} = \frac{\xi}{\rho};\ \frac{y}{r} = \frac{\eta}{\rho};\ \frac{z}{r} = \frac{\zeta}{\rho};\ r = \frac{1}{\rho}.$$

Substituting these values in the equation of the locus of the points f, we find for the equation of the polar reciprocal of the ray-surface

$$\frac{\xi^2}{\frac{1}{\rho^2} - a^2} + \frac{\eta^2}{\frac{1}{\rho^2} - b^2} + \frac{\zeta^2}{\frac{1}{\rho^2} - c^2} = 0$$

or

$$\frac{\frac{1}{a^2}\xi^2}{\rho^2 - \frac{1}{a^2}} + \frac{\frac{1}{b^2}\eta^2}{\rho^2 - \frac{1}{b^2}} + \frac{\frac{1}{c^2}\zeta^2}{\rho^2 - \frac{1}{c^2}} = 0$$

This is a surface of the same family as the ray-surface, being derived from the ellipsoid $\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1$ in the same way that the ray-surface itself is derived from the indicatrix $a^2x^2 + b^2y^2 + c^2z^2 = 1$.

The surface has been distinguished by Hamilton as the *surface of wave-slowness*, and by Mac Cullagh as the *index-surface*.[1]

[1] *Trans. Roy. Irish Acad.*: 1837, vol. 17, p. 142; 1839, vol. 18, p. 38.

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41. The optic bi-normals (*primary optic axes*).

From Article 25 it follows that if the section of the indicatrix by a plane having the direction of the ray-front is a circle, *every* point R on this section corresponds to a ray having the same direction of front and the same resolved velocity normal to the front, and therefore the same position of front. The normals of the indicatrix at the points R, and thus the planes of polarisation of the corresponding rays, may have any azimuth whatever.

That there are at least two directions of central section of the indicatrix for which the curve of section is a circle is seen as follows:—the section of the indicatrix by any plane OBP (Fig. 15), passing through the mean axis OB, is symmetrical both to the line $BO\overline{B}$ and the plane AOC, and therefore to $PO\overline{P}$, P being a point of intersection of the curve with the plane AOC: hence the section is in general an ellipse of which OB OP

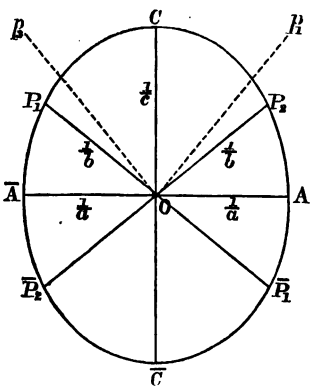

Fig. 15.

are the axes. If the direction OP be so taken in the plane AOC that the radius vector OP is equal to OB, which is always possible since OB is intermediate in length between OA and OC, the axes of the ellipse become equal and the ellipse becomes a circle.

There are only two directions for which a radius vector OP of the ellipse AOC has the value OB or $\frac{1}{b}$. If $x\,0\,z$ are the co-ordinates of P,

$$a^2x^2+c^2z^2=1, \text{ and } a^2+z^2=\frac{1}{b^2}: \text{ hence } \quad \frac{x^2}{b^2-c^2}=\frac{z^2}{a^2-b^2}.$$

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If $l\,0\,n$ be the direction-cosines of Op, the perpendicular to the line OP,

$$\frac{l}{n} = -\frac{z}{x}, \text{ and } \frac{l^2}{a^2-b^2} = \frac{n^2}{b^2-c^2}.$$

The angle pOC is given by the relation $\tan pOC = \pm\sqrt{\frac{a^2-b^2}{b^2-c^2}}$.

The two directions Op_1 Op_2 thus possess certain optical characters which in calcite and analogous crystals only belong to that single direction which is termed the optic axis: for ray-fronts normal to either Op_1 or Op_2 may have any azimuth of plane of polarisation whatever, and their velocities resolved normally to the direction of front are equal. By reason of this analogy, the directions Op_1 Op_2 have likewise been termed optic axes.

But the front-normals Op_1 Op_2 not being coincident with the corresponding rays, for they are not axes of the indicatrix, the directions Op_1 Op_2 do not possess all the characters which belong to the optic axis of a uniaxal crystal; to distinguish them from the directions Os_1 Os_2, which have been termed secondary optic axes, they have received the name *Primary Optic Axes*: they have also been termed by Sir William Hamilton *Lines of Single Normal-Velocity*.

Where precision of thought and language is necessary, the lines may conveniently be termed the *Optic Bi-normals*, for they are directions in which a line is doubly the central normal of a ray-front: the term is correlative to bi-radial, and such a bi-normal cannot be confused with that of a three-dimensional curve.

42. *There cannot be more than one pair of optic bi-normals.*

It has already been proved that the only bi-normals in the plane AOC are Op_1 Op_2: it remains to prove that there are no other bi-normals in any direction whatever.

From Article 33 we have for the relation between $l\,m\,n\,f$ the equation

$$\frac{l^2}{f^2-a^2} + \frac{m^2}{f^2-b^2} + \frac{n^2}{f^2-c^2} = 0,$$

or $l^2(f^2-b^2)(f^2-c^2) + m^2(f^2-c^2)(f^2-a^2) + n^2(f^2-a^2)(f^2-b^2) = 0.$

Since $a\,b\,c$ are in descending order of magnitude, the expression on the left-hand side of the last equation is positive, and therefore cannot be zero, if f has any value greater than a or less than c; as is otherwise evident from the fact that $f = \frac{1}{OR}$, where R is a point on the indicatrix: hence no value of f greater than a or less than c can make the expression zero.

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Further, if m is distinct from zero, the above expression is necessarily negative when $f = b$: hence it changes sign and passes through a zero value as f decreases from a to b, and again as f decreases from b to c. If m is distinct from zero, the two values of f^2 which satisfy the above equation are thus unequal.

Hence the bi-normals can only lie in the plane AOC.

Since OB is normal to the plane of polarisation for any ray-front of which the normal lies in the plane AOC, one root of the equation corresponding to such a ray-front is always $f=b$, and this must be the value of the equal roots: the directions of the bi-normals may therefore be found directly from the general equation (Art. **33**) as follows:—

For any front-normal in the plane AOC, $m=0$, and the values of f^2 are given by the equation $\frac{l^2}{f^2-a^2} + \frac{n^2}{f^2-c^2} = 0$: hence, the directions of the front-normals in the plane AOC for which $f = b$ are given by the equation $\frac{l^2}{a^2-b^2} = \frac{n^2}{b^2-c^2}$; which is identical with the equation of last Article.

43. *The direction of a line Of being defined by its inclinations π_1 π_2 to the bi-normals Op_1 Op_2, to find the transverse planes of the two rays of which the corresponding fronts are perpendicular to the given line.*

Let $[p_1]$ $[p_2]$ be the circular sections of the indicatrix perpendicular to the bi-normals Op_1 Op_2 respectively, and let $[f]$ be the central section of the indicatrix parallel to the given direction of ray-front (Fig. 16).

Let $[f]$ intersect $[p_1]$ $[p_2]$ in E_1 E_2 respectively.

All radii vectores in the two circular sections being equal, $OE_1 = OE_2$: and the axes OR OT of the elliptical section $[f]$ are therefore the internal and external bisectors of the angle E_1OE_2.

By Art. **26** the two rays Or Ot corresponding to the front-normal Of are in the planes fOR fOT respectively.

Again, Of is perpendicular to both OE_1 and OE_2;

Op_1 Op_2 are perpendicular to OE_1 and OE_2 respectively.

Hence OE_1 is perpendicular to both Of and Op_1, and therefore to their plane fOp_1;

OE_2 is perpendicular to both Of and Op_2, and therefore to their plane fOp_2.

The planes fOE_1 fOp_1 are thus at right angles: likewise the planes fOE_2 fOp_2.

Hence the planes fOR fOT which bisect the angles between fOE_1 and fOE_2, also bisect the angles between fOp_1 fOp_2, the planes which pass

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through Of and the bi-normals Op_1 Op_2. In other words each of the perpendicular planes, which bisect the angles between the two planes passing through Of and one or other of the bi-normals, contains one of the rays of which the front is normal to Of, and is the *transverse* plane of the contained ray. As already pointed out in Art. **26**, it is the transverse planes, not the planes of polarisation, of the two rays corresponding to a single direction of front-normal which are perpendicular to each other.

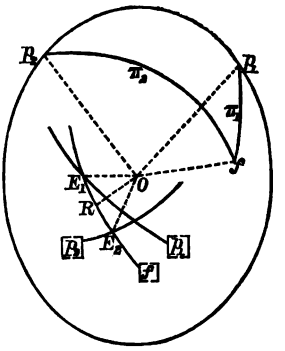

FIG. 16.

44. *The direction of a line Of being defined by its inclinations π_1 π_2 to the bi-normals Op_1 Op_2, to find f_1 f_2 the velocities of normal-transmission of the two ray-fronts which are perpendicular to the given line.*

From the equation of Art. **33**, it follows that

$$f_1^2+f_2^2=l^2(b^2+c^2)+m^2(c^2+a^2)+n^2(a^2+b^2)$$
$$f_1^2f_2^2=l^2b^2c^2+m^2c^2a^2+n^2a^2b^2.$$

Hence, proceeding by the method of Art. **20**, it may be shown, having due regard to the relative magnitudes of f_1 and f_2, that

$$f_1^2-f_2^2=(a^2-c^2)\sin\pi_1\sin\pi_2, \text{ and that}$$
$$2f_1^2=a^2+c^2+(a^2-c^2)\cos(\pi_1-\pi_2)$$
$$2f_2^2=a^2+c^2+(a^2-c^2)\cos(\pi_1+\pi_2):$$

whence

$$f_1^2=a^2\cos^2\frac{\pi_1-\pi_2}{2}+c^2\sin^2\frac{\pi_1-\pi_2}{2},$$

$$f_2^2=a^2\cos^2\frac{\pi_1+\pi_2}{2}+c^2\sin^2\frac{\pi_1+\pi_2}{2}.$$

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45. The bi-radial cone (*the cone of front-normals which correspond to the rays transmissible along a bi-radial*).

We have seen (Article **11**) that in general for any given direction of ray Or there are four corresponding points of the indicatrix on two diameters OR_1 OR_2 of the conjugate plane. Also (Article **27**), there are two corresponding front-normals Of_1 Of_2, lying in the planes OrR_1 OrR_2 and perpendicular to OR_1 OR_2 respectively. But we have seen that in the case of a bi-radial Os_1, every point S on the conjugate section corresponds to a ray transmissible along that direction with the velocity b. Further, Os_1 is not an axis of the indicatrix, and thus is only coincident with the corresponding central normal On for the two rays transmissible in the direction Os_1 which correspond to the two points $B\,\overline{B}$ in which the axis $BO\overline{B}$ meets the conjugate section.

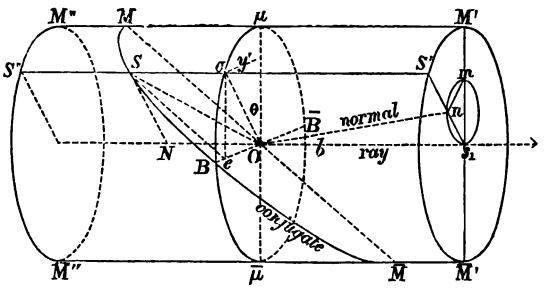

FIG. 17.

If $M''\overline{M}'$ (Fig. 17) be the right circular cylinder touching the indicatrix in the curve $MS\overline{M}$, in which the plane conjugate to the bi-radial Os_1 meets the indicatrix, and $M'S'\overline{M}'$ be a basal section perpendicular to the axis, the front-normal On, corresponding to any point S on the curve, is in the plane $SS's_1$ passing through the axis of the cylinder, and is at right angles to OS. Hence, as the point S moves round the curve $MB\overline{M}$, the corresponding normal On describes a cone of which the bi-radial Os_1 is an edge, for it corresponds to the points B $\overline{B}$ on the curve: the cone may be conveniently designated a *bi-radial cone*. In the next Article it will be shown that the bi-radial cone intersects the base of its corresponding cylinder in a circle.

Corollary. Since the front corresponding to a ray touches the ray

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surface at the point where the ray meets it, a cone of tangent planes can be drawn at each of the points in which a bi-radial meets the ray-surface.

46. *A plane perpendicular to a bi-radial intersects the cone of corresponding front-normals in a circle.*

First proof.

Taking the base of the cylinder at such a distance from O that $Os_1 = b$, we have $ns_1 = Os_1 \tan nOs_1$ (Fig. 17), for the angle ns_1O is by construction a right angle.

Also, by construction, $SN = \dfrac{1}{Os_1} = \dfrac{1}{b}$.

Hence $\tan nOs_1 = \tan OSN = \dfrac{ON}{NS} = b \cdot ON$,

and $ns_1 = b^2 \cdot ON$.

Let $B\mu\overline{B}$ be a section of the cylinder parallel to the base, and let the line SS' intersect the curve μB in the point σ: further let MOs_1 be the symmetral plane of the indicatrix which contains the axes OA OC, and Om be the direction of the front-normal corresponding to the point M on the indicatrix.

SN and σO are equal and parallel, since they are both normal to the axis of the cylinder and in a plane containing it: hence $ON = S\sigma$.

Draw Se σe perpendicular to the axis OB; and let the angle between the conjugate section and the base of the cylinder be ϕ: then

$$Se\sigma = MO\mu = mOs_1 = \phi.$$

Let the angle ns_1m be denoted by θ: to determine the relation between ns_1 and the angle θ, we thus require to express ON or $S\sigma$ in terms of the angle ns_1m or $\sigma O\mu$.

We have $S\sigma = \sigma e \tan\phi = O\sigma \cos\theta \tan\phi = \dfrac{1}{b}\cos\theta \tan\phi$.

Hence $ns_1 = b^2 \cdot ON = b^2 \cdot S\sigma = b \cos\theta \tan\phi = s_1m \cos\theta$.

The angle mns_1 is thus a right angle; and the locus of n is a circle passing through the point s_1, and having ms_1 for diameter.

Second proof.

Let $x'y'z'$ be the co-ordinates of any point S on the section conjugate to the bi-radial Os_1: by Article **18**

$$\frac{x'^2}{a^2(b^2-c^2)} = \frac{z'^2}{a^2(a^2-b^2)}.$$

Now y', being the perpendicular from S or σ to the plane $M\mu M's_1$, is equal to

$$\sigma O \sin\mu O\sigma = \frac{\sin\theta}{b}.$$

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Finding $x'z'$ also in terms of θ by means of the above equation, we have

$$x'^2 = \frac{b^2-c^2}{a^2-c^2}\frac{\cos^2\theta}{a^2}; \qquad z'^2 = \frac{a^2-b^2}{a^2-c^2}\frac{\cos^2\theta}{c^2}.$$

Also $s_1n^2 = On^2 - Os_1^2$.

Draw s_1f parallel to OS and therefore perpendicular to On:

then $On = \frac{Os_1^2}{Of} = b^2 \cdot OS$, for $Of = \frac{1}{OS}$ (Art. 23).

Hence $s_1n^2 = b^4OS^2 - b^2$.

$$= b^4(x'^2+y'^2+z'^2) - b^2$$

Substituting the above values of $x'\ y'\ z'$ in terms of θ, we get

$$s_1n = \frac{b\cos\theta}{ac}\sqrt{(a^2-b^2)(b^2-c^2)}, \text{ or}$$

$s_1n = k\cos\theta$, where k is constant for all values of θ.

For $\theta = 0$, n takes the position m; hence $s_1n = s_1m\cos\theta$, as before.

Also $s_1m = k = \frac{b}{ac}\sqrt{(a^2-b^2)(b^2-c^2)}$.

47. *Aperture of the bi-radial cone.*

If the angle mOs_1 be termed the *aperture* of the cone, the aperture is given by the relation

$$\tan mOs_1 = \frac{s_1m}{s_1O} = \frac{1}{ac}\sqrt{(a^2-b^2)(b^2-c^2)}.$$

The angle mOs_1 is the angle between Os_1, a bi-radial, and Om, a line perpendicular to the plane which is conjugate to that bi-radial; a relation by means of which the above value may likewise be obtained.

48. *Polarisation of the ray corresponding to a given front-normal of the bi-radial cone.*

For the ray transmissible along Os_1 which has On for its front-normal, the normal of the plane of polarisation is SN or ns_1: hence the plane of polarisation of that ray Os_1 which has On for its front-normal, meets the base of the cone in a line parallel to the line nm, or in other words in the line which joins s_1 to the other extremity of that diameter of the circle which passes through n.

49. **The bi-normal cone** (*the cone of rays corresponding to a front which is perpendicular to a bi-normal*).

In general (Article 26), if $OR\ OT$ (Figs. 18, 18) be the axes of a central section of the indicatrix, the points $R\ T$ correspond to rays $Or\ Ot$ having fronts in the same direction, namely parallel to the plane ORT: also, if Of be the normal to the fronts, the rays $Or\ Ot$ lie in the planes fOR fOT and are perpendicular to the lines which are normal to the indicatrix

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at R and T respectively. But we have seen that all points on the circular section perpendicular to a bi-normal Op_1 correspond to rays having the same position and direction of front, the latter being parallel to the circular section: further Op_1 is not an axis of the indicatrix, and thus is only coincident with the corresponding ray for the two points $B\,\overline{B}$ on the circular section.

Hence, as the point R moves round the circular section of the indicatrix, the ray Or, which is always in the plane ROp_1, describes a cone of which the bi-normal Op_1 is an edge, for it corresponds to the points $B\,\overline{B}$ on the curve. The cone may be conveniently designated a *bi-normal cone*.

Corollary. Since every front touches the ray-surface where the corresponding ray meets it, a bi-normal is perpendicular to a plane which touches the ray-surface in a closed curve. In the next Article it will be shown that this curve is a circle.

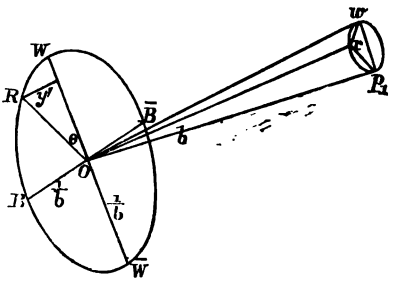

FIG. 18.

50. *A plane perpendicular to a bi-normal intersects the cone of corresponding rays in a circle.*

Let $W\overline{W}$ (Fig. 18) be the points where the circular section intersects the plane AOC: let $Op_1=b$, and R be any point on the circular section: the plane ROp_1, containing the ray Or corresponding to the point R, will intersect a plane, drawn through p_1 parallel to the circular section, in a line p_1r parallel to OR; similarly, if Ow be the ray corresponding to the point W, p_1w is parallel to OW: hence the angle rp_1w = angle ROW. Denote it by θ.

Also

$$p_1r^2 = Or^2 - Op_1^2$$
$$= a^4x'^2 + b^4y'^2 + c^4z'^2 - b^2, \text{ if } x'y'z' \text{ be the co-ordinates of the point } R \text{ (Article 4).}$$

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But y' being the perpendicular from R on the plane WOp_1 or AOC, we have $$y' = OR \sin WOR = \frac{\sin\theta}{b}.$$

Also, since R is on a circular section,

$$\frac{x'^2}{b^2-c^2} = \frac{z'^2}{a^2-b^2} \text{ (Article 41)}$$

Finding x' and z' in terms of θ by means of this equation and the relation $a^2x'^2+b^2y'^2+c^2z'^2=1$, we get

$$x'^2 = \frac{b^2-c^2}{a^2-c^2}\frac{\cos^2\theta}{b^2} \qquad z'^2 = \frac{a^2-b^2}{a^2-c^2}\frac{\cos^2\theta}{b^2}$$

Substituting these values of x'^2, y'^2, z'^2 in the equation for p_1r, we have $$p_1r = \frac{\cos\theta}{b}\sqrt{(a^2-b^2)(b^2-c^2)}, \text{ or}$$

$p_1r = l\cos\theta$, where l is a constant for all values of θ.

For $\theta = 0$, r takes the position w:

$$\text{hence } p_1r = p_1w\cos\theta; \text{ and } p_1w = \frac{1}{b}\sqrt{(a^2-b^2)(b^2-c^2)}.$$

The angle p_1rw is thus a right angle; hence the locus of r is a circle passing through the point p_1 and having p_1w for diameter.

The section of the cone of rays by a plane perpendicular to that bi-normal which is the front-normal for the rays is therefore a circle.

51. *Aperture of the bi-normal cone.*

If the angle wOp_1 be termed the aperture of the cone, the aperture is given by the relation

$$\tan wOp_1 = \frac{p_1w}{p_1O} = \frac{1}{b^2}\sqrt{(a^2-b^2)(b^2-c^2)}.$$

The angle wOp_1 is equal to the angle between the radius-vector OW and the normal of the indicatrix at W, for Op_1 and Ow are respectively perpendicular to OW and the normal at W; a relation by means of which the above value may likewise be obtained.

52. *Polarisation of the rays of the bi-normal cone.*

The plane of polarisation of the ray Or is a plane perpendicular to the transverse plane Op_1r. The line Op_1, being perpendicular to the plane p_1rw, is perpendicular to the line joining p_1 to r, the other extremity of that diameter of the circle p_1rw which passes through r; the line rp_1, being perpendicular to both p_1O and p_1r, is perpendicular to the plane Op_1r containing them: as any plane passing through p_1r, or its parallel rw, is likewise perpendicular to the plane Op_1r, the plane Orw is the plane of polarisation of the ray Or.

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53. Representative surfaces derived from the Indicatrix.

(*a*) The characters of a ray of light transmitted in a crystal may also be expressed by reference to corresponding points on the polar reciprocal of the indicatrix relative to a concentric sphere: this surface is an ellipsoid represented by the equation $\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}=1$ (p. 381 and Fig. 19).

If OR, a radius vector of the indicatrix, be normal to a tangent plane of the polar reciprocal of the indicatrix, meeting the plane in a point M, $OR \cdot OM=1$, if the radius of the reciprocating sphere be unity. If P be the point in which the tangent plane perpendicular to OR touches the polar reciprocal, and PG be the normal of the latter surface at the point P, the lines PG PO lie in the plane $RNOr$: let PG intersect the ray Or in the point G. If m be the point in which OP intersects the plane which touches the indicatrix at R, $OP \cdot Om = 1$, and OP is thus the inverse of RN. Hence, to every point P on the polar reciprocal of the indicatrix corresponds a ray Or: it lies in the plane $PGOr$, and is perpendicular to OP: its velocity of transmission is measured by OP: its transverse plane is $PGOr$: the ray-front intersects the transverse plane $PGOr$ perpendicularly in a line parallel to PG, and its velocity of normal-transmission is measured by PG.

(*b*) Von Lang[1] has pointed out that if a surface be derived from the ellipsoid $a^2x^2+b^2y^2+c^2z^2=1$ by elongating each radius vector until the new length is measured by the nth power of its original value, the derivative surface may likewise be used for the geometrical representation of the characters of transmitted rays. This result can be generalised still farther, as follows:—

Let $\phi^{-1}(r)$ be any function of r, which always increases and decreases with r, or *vice versâ*: it will have an apsidal (*i.e.* maximum or minimum) value at the same time as r. If then a new surface be derived by elongating each radius vector r of the indicatrix to a length ρ, determined by the relation $\rho=\phi^{-1}(r)$ or $r=\phi(\rho)$, a central section of the new surface will have its apsidal diameters in exactly the same directions as those of the section of the indicatrix by the same plane. If ρ_1 ρ_2 be the half-lengths of the new diameters, the corresponding ray-fronts are respectively at distances $\frac{1}{r_1}$ and $\frac{1}{r_2}$ or $\frac{1}{\phi(\rho_1)}$ and $\frac{1}{\phi(\rho_2)}$ from the central section; the ray-surface itself is the envelope of these planes.

[1] *Sitz. Ak. Wien*, 1861, vol. 43, sec. 2, p. 645.

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The general equation of the new surface is easily found:—

If r be the length of a radius vector of the indicatrix and $l\ m\ n$ be its direction-cosines, $a^2l^2+b^2m^2+c^2n^2=\frac{1}{r^2}$; $\xi\ \eta\ \zeta$ being the co-ordinates of the corresponding point on the new surface, $\xi=l\rho$, $\eta=m\rho$, $\zeta=n\rho$:

$$\text{whence } a^2\xi^2+b^2\eta^2+c^2\zeta^2=\frac{\rho^2}{r^2}$$

$$\text{or } a^2\xi^2+b^2\eta^2+c^2\zeta^2=\frac{\rho^2}{[\phi(\rho)]^2};$$

which is the required equation.

Fresnel's "surface of elasticity" is the particular case in which $\phi(\rho)=\frac{1}{\rho}$, for the equation then becomes $a^2\xi^2+b^2\eta^2+c^2\zeta^2=(\xi^2+\eta^2+\zeta^2)^2$.

For the "surface of elasticity," the transverse planes of the rays corresponding to a given direction of ray-front pass through the apsidal diameters of a central section, as in the case of the indicatrix, but the distance of the ray-front corresponding to a semi-diameter of length ρ_1 is not $\frac{1}{\rho_1}$ as in the indicatrix, but $\frac{1}{\phi(\rho_1)}$ or ρ_1.

The corresponding ray is only perpendicular to the corresponding normal of the representative surface in the case of the indicatrix: in every case, however, the normal of the representative surface lies in the plane passing through the corresponding diameter and the front-normal: for the curves of intersection of the two surfaces by the given plane have parallel tangents at the extremities of their maximum and minimum diameters. Hence, as in the case of the indicatrix, the plane passing through a diameter and a normal of the surface at the extremity of the diameter is the *transverse* plane of the corresponding ray.

(*c*) In exactly the same way a series of surfaces can be derived from the polar reciprocal of the indicatrix.

The above generalisation serves as a reminder that there is not *necessarily* a simple relation between a surface of geometrical representation and the characters of the ether.

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Section V.—Various Optical Relations which are independent of the Physical Character of the Periodic Change.

1. In Section II we have shown that after the discovery of the polarisation of light by reflection by Malus in 1808, and of the correspondence of optical and morphological symmetry by Brewster in 1819, the true laws of transmission of light in biaxal crystals must soon have been suggested, independently of any hypothesis as to the physical character of the periodic change: in fact, their enunciation by Fresnel in 1821 was only two years later than Biot's discovery of two empirical laws by which the accuracy of a geometrical representation could be tested. If the truth of the construction given by Huygens for the case of calcite is acknowledged, the suggestion presents itself as soon as the planes of polarisation of the two rays transmissible in any direction in a crystal of calcite are represented by their normals.

In the present Section we proceed to indicate very briefly, for the convenience of the student, various other important relations, which, though really independent of any hypothesis as to the nature of the periodic change, are usually imagined and expressed as belonging to an elastic ether. It will at the same time be shown that the form of the ray-surface for biaxal crystals is not merely suggested by a geometrical generalisation as a tentative one, but is a necessary consequence of the difference of symmetrical development of the same physical characters, whatever they may be, which originate the sphere and spheroid of a uniaxal crystal: it will further be shown that the same form of the ray-surface would result from the general features of perpendicularly transverse undulations, and be independent of the real nature of the periodic change.

Preliminary algebraical expression for the transmission of a ray of ordinary light.

2. It will be convenient, in the first place, to find a mathematical expression connecting the magnitude of the disturbance or change of state at any point in a ray of ordinary light of simple colour with the position of the point, the time, and the period of the vibration. For this purpose it is necessary to make an assumption as to the law of the change: the simplest which can be made is that at any point of a ray of ordinary light

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of simple colour the variation of the state with the time follows the same law as the variation of position of an isochronous pendulum.

It will be found that, for a ray of simple colour, the expression

$$y = a\sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha\right\}$$

is one which satisfies this condition and is consistent with all experiments *as yet referred to*;

x denoting the distance of any point in the ray from a fixed point in it,

y the magnitude of the disturbance or change of state at the point x at the time t;

v the velocity of transmission,

λ the wave-length,

a and α two constants for all values of x and t:—

1. At a given *point*, indicated by its distance x from the origin, the change of state varies periodically with the time t: the same value of y, and therefore the same change of state, recurs whenever the expression $\frac{2\pi}{\lambda}(vt-x)+\alpha$ increases by 2π, that is when t increases by the constant interval $\frac{\lambda}{v}$. The same change of state recurs, but with opposite sign, whenever the expression $\frac{2\pi}{\lambda}(vt-x)+\alpha$ increases by π, that is when t increases by half the above interval.

2. At a given *instant*, indicated by the time t, the change of state is the same in magnitude and sign for all points separated from each other by the distance λ: it is the same in magnitude and opposite in sign for all points separated from each other by half that distance.

3. The relation between y and t is identical with the relation between the position of an isochronous pendulum and the time.

a, being the maximum value of y, is the amplitude of the vibration.

$\frac{2\pi}{\lambda}(vt-x)+\alpha$ being the phase of the vibration at the point x at the time t, α is the phase of the vibration at the origin ($x=0$) at the epoch from which the time is measured ($t=0$).

The period of the vibration being independent of the amplitude, the law is consistent with the independence of colour and intensity.

Conversely, if the magnitude of the change of state at each point of a line is given by the expression $y=a\sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha\right\}$, and the change is of the physical character which belongs to light, a ray of light of simple

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colour is passing along the line with a velocity v: the intensity corresponds to the amplitude a, the colour to the period $\frac{\lambda}{v}$, while the phase of the vibration at the origin at the initial epoch is α.

From analogy with sound, we may tentatively assume that the intensity of the light corresponding to this simple change of state is measured by the square of the amplitude.

Resultant effect of the simultaneous transmission of two or more such rays along the same line.

3. The fact of the periodicity of the change was deduced from experiments relative to the mutual interference of rays of light: it is easily seen that the above expression for the change, combined with the principle of superposition, is consistent with the observed phenomena from which it was deduced.

(*a*) *If the component rays have the same wave-length and velocity.*

1. For let two rays of the same simple colour, transmissible along a given line with the same velocity v, be represented respectively by the expressions

$$y = a \sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha\right\}$$

$$y = b \sin\left\{\frac{2\pi}{\lambda}(vt-x)+\beta\right\}:$$

if both are transmitted simultaneously, the principle of superposition requires the resultant change to be determined by the expression

$$y = a \sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha\right\} + b \sin\left\{\frac{2\pi}{\lambda}(vt-x)+\beta\right\}.$$

If the terms can be added together *in the same way as numerical quantities of a single kind*,

$$y = (a\cos\alpha + b\cos\beta)\sin\frac{2\pi}{\lambda}(vt-x) + (a\sin\alpha + b\sin\beta)\cos\frac{2\pi}{\lambda}(vt-x)$$

$$= c \sin\left\{\frac{2\pi}{\lambda}(vt-x)+\gamma\right\},$$

if $$c^2 = a^2 + b^2 + 2ab\cos(\alpha-\beta)$$

and $$\tan\gamma = \frac{a\sin\alpha + b\sin\beta}{a\cos\alpha + b\cos\beta}.$$

Hence the resultant effect of the two rays is identical with that of a single ray transmitted along the same line with the same velocity and the same wave-length (and thus of the same colour), but having an intensity c^2 and an original phase γ. And the intensity of the resultant ray depends

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not only on the intensities of the component rays but on their difference of phase at the same point at the same instant: if a and b are equal and α differs from β by any odd multiple of π, the intensity of the single resultant ray is constantly zero.

2. It may in this way be shown that the resultant effect of the simultaneous transmission of any number of such rays of the same simple colour along the same line with the same velocity is identical with that of a single ray of the same colour and velocity, and having a determinable phase and intensity.

(*b*) *If the component rays differ in wave-length or velocity.*

On the other hand, if the component rays differ either in velocity or wave-length, the resultant effect is not that of a single ray of simple colour: the resultant effect is still expressed by

$$a \sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha\right\}+b \sin\left\{\frac{2\pi}{\lambda'}(v't-x)+\beta\right\};$$

but the expression cannot take the simpler form $c\sin\left\{\frac{2\pi}{\lambda''}(v''t-x)+\gamma\right\}$, in which c and γ are both constants: indeed, the resultant effect is not periodic at all unless the ratio $\frac{v}{\lambda}:\frac{v'}{\lambda'}$ is commensurable.

Kinematical representation of the periodic change at any point of such a ray.

4. Whatever be the physical character of the periodic change at any point of a ray of light, the state at any point P at a given instant may thus (consistently with any facts as yet indicated) be represented by the above expression

$$y=a \sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha\right\}:$$

this algebraical expression may in turn be represented geometrically; the magnitude y being represented by the distance of a point p from the point P, and the distance being considered positive or negative according to the direction in which it is measured. The phenomena of interference, from which the above expression has been deduced, merely require the direction in which the line Pp is measured to be necessarily the same for all points of the same ray, and for all interfering rays transmitted along the same line.

This mode of representation in no way assumes that the *actual* change of state at the point P is a to-and-fro motion of a particle of ether in the arbitrary line Pp; the direction of the line Pp is required to be constant merely to secure that the changes, if they have any directional character

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at all, may be added together like simple numerical quantities of the same kind: that the change is really directional in character may be inferred from the fact that it is being transmitted in a definite direction through the medium. In exactly the same way, the transmission of a ray of light along a line is sometimes conveniently represented (in the discussion of aberration, for instance) by the transmission of a point along the line with constant velocity, although light is certainly not due to the transmission of a particle along the direction of the ray.

Preliminary algebraical expression for the transmission of a ray of plane-polarised light.

5. It was found by Fresnel, in conjunction with Arago, that two rays of plane-polarised light, if their planes of polarisation are parallel, *may* mutually interfere in exactly the same way as ordinary light: hence, as far as this experiment goes, the periodic change at any point of a plane-polarised ray can be represented in exactly the same way as for ordinary light; the only difference being that while an ordinary ray is so far analogous to a circular cylinder that its characters are identical on all its sides, a plane-polarised ray is analogous to an elliptical cylinder to the extent that the properties of the ray are dissimilarly symmetrical relative to two perpendicular planes (pages 288 and 293).

If all the characters of a plane-polarised ray can be accounted for by such a kinematical representation as is mentioned above, the line Pp must lie either in the plane of polarisation or the transverse plane ; but it may have any inclination whatsoever to the ray, so long as for two interfering rays the direction is identical.

More general representation of the periodic change at any point of an ordinary or plane-polarised ray.

6. Since, as far as the above experiments are concerned, the inclination of the direction Pp to the line of transmission of either a plane-polarised or an ordinary ray, may be any whatsoever, it follows that the change may really not be simple, but *multiple* in direction; assuming that each transmitted periodic change will interfere for itself, as if those having other directions did not exist.

In fact, it will be seen that the periodic change may likewise be represented by the composite expression

$$y = a_1 \sin\left\{\frac{2\pi}{\lambda}(vt-x)+a_1\right\}+\ldots\ldots\ldots+a_n \sin\left\{\frac{2\pi}{\lambda}(vt-x)+a_n\right\}$$

consisting of any number of terms: for each separate term, independently

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of its directional relations, resumes its original value at distances along the ray separated from each other by the common length λ, or at times separated from each other by the common period $\frac{\lambda}{v}$: hence, if two rays annihilate each other under given circumstances, annihilation will again take place if one of the rays is moved *parallel to itself* through the distance λ along its line of transmission.

And it is important to remark that as each term recurs *individually* after the same interval of time or distance, the whole expression likewise recurs and has the same total value, even if the terms are *not* subject to the same law of addition as simple numerical quantities.

It will also be obvious on reflection that any ray which is within the reach of experiment is necessarily composite as regards the origin of its vibration, even if it be simple as regards its colour: the luminous source is not a geometrical point, but a surface of considerable dimensions as compared with the wave-length of a ray of light; hence the periodic change, of which the effects are observed at a given point of a line of transmission, is really of composite origin and due to the superposition of the periodic changes transmitted from the points of a luminous area of appreciable magnitude.

As for the difference between an ordinary and a plane-polarised ray, the first suggestion which presents itself is that the latter is due to the distortion of the ordinary ray from which it was derived; just as an elliptical cylinder may be derived from a circular cylinder by compression in a direction inclined to the axis.

Experimental discovery made by Fresnel and Arago.

7. (*a*) But Fresnel and Arago found that, when one of two interfering plane-polarised rays is turned through a right angle round its direction of transmission, the interference-effects completely disappear, whatever the difference of phase of the two rays. Hence, with this relative position of the planes of polarisation, the periodic change produced at any point by the transmission of one ray is in no direction coincident with a periodic change produced by the transmission of the other ray; for as we have seen (Art. 3), such coincidence would involve a variation of intensity of the resultant effect: if this be granted, it follows that for a plane-polarised ray the actual periodic change must be in only a single direction, and the single direction must be perpendicular to the line of transmission; for otherwise the two positions of the plane-polarised ray would give two positions of the periodic change which would have a resolved part in

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common. Since the direction is single, it must be in one of the symmetral planes of the ray: hence the direction of the actual periodic change is perpendicular to the direction of transmission, and may be either in or perpendicular to the plane of polarisation: in either case it may be *represented* by a line perpendicular to the plane of polarisation.

In the above experiments of Fresnel and Arago, the rays were allowed to interfere during aerial transmission; it may reasonably be assumed, however, that the same kind of symmetry with respect to two perpendicular planes obtains for a plane-polarised ray as transmitted within any crystalline medium: the assumption is not only reasonable on general grounds, but is consistent at once with all known experimental results and with the requirements of the most recent version of the elastic theory (see also pages 293, 308). It is not the only assumption which can be made: Fresnel himself was led by the hypothesis of an incompressible elastic ether to infer that a plane-polarised ray transmitted within a bi-refractive medium is in general symmetrical to only a single plane, perpendicular to the plane of polarisation; he inferred, in fact, that the vibrations of the ether lie in the transverse plane and are in general oblique, not perpendicular, to the direction of the ray. That Fresnel felt the unsatisfactory character of the inference, in the absence of any experimental proof of the obliquity, will be seen on reference to the original memoir.[1]

(*b*) If the two polarised rays which have been obtained from a ray of ordinary light by means of a crystal of calcite are transmitted along the same line, it is found that the resultant effect is again that of a single ray of ordinary light: hence we may infer that in ordinary light, as in plane-polarised light, the vibrations are perpendicular to the direction of transmission of the ray.

Representation of the resultant effect of the simultaneous transmission along the same line of two or more plane-polarised rays having different directions of planes of polarisation.

8. (*a*.) *If the component rays have the same wave-length and velocity.* (1.) The periodic change at any point of a plane-polarised ray being kinematically represented by a vibration perpendicular to the plane of polarisation, let two rays be transmitted with the same velocity along the same line, having different directions of the plane of polarisation: and, in the first place, let the algebraical expressions for the corresponding changes be respectively

$$y = a \sin\left\{\frac{2\pi}{\lambda}(vt - x) + \alpha\right\} \text{ and } z = b \sin\left\{\frac{2\pi}{\lambda}(vt - x) + \beta\right\}.$$

[1] *Loc. cit.*; 1827, p. 158.

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Assuming as before the principle of superposition, the effect of transmitting both rays simultaneously will be represented by the motion of a point of which the co-ordinates y and z, measured along the normals of the planes of polarisation, are given by the expressions

$$y = a \sin\left\{\frac{2\pi}{\lambda}(vt - x) + \alpha\right\}$$

$$z = b \sin\left\{\frac{2\pi}{\lambda}(vt - x) + \beta\right\}.$$

Eliminating $\frac{2\pi}{\lambda}(vt - x)$, we find

$$\frac{y^2}{a^2} + \frac{z^2}{b^2} - \frac{2yz}{ab}\cos(\alpha - \beta) = \sin^2(\alpha - \beta).$$

Hence the point, of which the position at any instant represents the resultant disturbance at that instant at a corresponding point on the line of transmission, describes in general an ellipse, of which the magnitude and position relative to the planes of polarisation of the original rays are independent both of x and t: all the ellipses are thus equal and parallel, and form a cylinder of which the base is elliptical, and the axis is in the direction of transmission. It will be found that the direction in which the point moves round the ellipse is determined by the relative phases of the two rays. The composite or resultant ray of light due to the co-existence of the original rays is said to be *elliptically polarised*; a ray of which the characters are related to a cylinder with elliptical base must differ from a ray of ordinary light, of which the characters are the same on all its sides.

(2.) If the rays have the same intensity, and their difference of phase is measured by the angle between their planes of polarisation, $a = b$, and $\alpha - \beta$ is equal to the angle between the directions of y and z: in this case the ellipse becomes a circle, and the cylinder becomes one with a circular base. The composite ray is then said to be *circularly polarised*. Such a ray is similarly related to every plane passing through it, and yet differs from one of ordinary light: for the motion of the representative point is not symmetrical to a plane, and the characters of the ray may conceivably differ with the direction in which the circle is described by the ideal point. In fact, experimental methods enable us to distinguish, not only between a ray of ordinary light and one which is circularly polarised, but between two circularly polarised rays of which the motion of the ideal point is in opposite directions.

(3.) If $\sin(\alpha - \beta) = 0$, that is to say, if the difference of phase is zero or a multiple of π, the ellipse becomes one or other of the two straight lines

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$\left(\frac{y}{a}\pm\frac{z}{b}\right)^2=0$: hence the resultant ray is itself *plane-polarised*, the direction of the plane of polarisation depending on the ratio $a:b$, and thus being determined by the relative intensities of the two component rays. Conversely, such a single plane-polarised ray of simple colour is equivalent in its effects to two such plane-polarised rays of the same simple colour, transmitted along the same line with the same velocity, and with their planes of polarisation in *any* assigned directions. If the two assigned directions be perpendicular to each other, and θ be the inclination of one of them to the plane of polarisation of the original ray supposed to be represented by the expression

$$y=a\sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha\right\},$$

the two equivalent rays are represented respectively by the expressions

$$y=a\sin\theta\sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha\right\}$$

$$z=a\cos\theta\sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha\right\};$$

for the resultant effect of these two rays is such that

$$\frac{y}{z}=\tan\theta, \text{ a constant quantity,}$$

whatever be the time or the position of the point in the line of transmission.

(4.) Further, it will be seen that any number of such rays of the same simple colour transmitted along the same line with the same velocity but with different phases, amplitudes and planes of polarisation, will have a resultant effect identical in general with that of a single elliptically polarised ray of the same simple colour, transmitted along the same line with the same velocity. For let the simple rays be severally represented by the expressions

$$y_1=a_1\sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha_1\right\}$$

$$y_2=a_2\sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha_2\right\}$$

.....

$$y_n=a_n\sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha_n\right\},$$

and let the inclinations of the respective planes of polarisation to a fixed

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plane of reference through the line of transmission be $\theta_1\ \theta_2 \ldots\ \ldots\theta_n$. Each single ray being equivalent in effect to two rays with perpendicular planes of polarisation, one of them coincident with the fixed plane of reference, the whole system of rays is equivalent to the following two systems:—

$$y = a_1 \sin\theta_1 \sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha_1\right\} + \ldots\ldots + a_n \sin\theta_n \sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha_n\right\}$$

$$z = a_1 \cos\theta_1 \sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha_1\right\} + \ldots\ldots + a_n \cos\theta_n \sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha_n\right\};$$

all the members of each of these systems having a common direction of plane of polarisation.

As each system is equivalent to a single plane-polarised ray (Arts. 3 and 5), the two systems are together equivalent in general to a single elliptically polarised ray.

(5.) Whether the resultant ray be elliptically, circularly, or plane-polarised, the resultant change has the same period as the change for each component ray, and is thus of unaltered colour.

(6.) At a given instant, the ideal points representing the state at all points of the resultant ray lie on a spiral curve surrounding the elliptical or circular cylinder, if the ray be elliptically or circularly polarised, and on an undulating curve (the curve of sines) in the transverse plane, if the ray be plane-polarised.

(*b*.) *If the component rays differ in wave-length or velocity.*

If the two component rays differ in wave-length or velocity of transmission, the resultant effect is still represented by the combined expressions

$$y = a \sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha\right\}$$

$$z = b \sin\left\{\frac{2\pi}{\lambda'}(v't-x)+\beta\right\}:$$

but it is not periodic at all unless the ratio $\frac{v}{\lambda} : \frac{v'}{\lambda'}$ is commensurable: and even in that case the curve described by an ideal point is not a conic section.

The resultant effect can only be that of a plane-polarised ray if the ratio of y to z, and therefore of $\sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha\right\}$ to $\sin\left\{\frac{2\pi}{\lambda}(vt-x)+\beta\right\}$ is independent of the time: but if either v or λ is different from v' or λ' respectively, this constancy is impossible, whether the planes of polarisation of the original rays are real or imaginary.

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Discrepancy of observed and calculated results.

9. But the above calculation of the resultant effect of the simultaneous transmission along the same line of two plane-polarised rays of the same colour with planes of polarisation at right angles to each other is in direct disagreement with the experimental result recorded in Art. 7*b*, for the result of superposition of the two plane-polarised rays obtained from an ordinary ray by means of a bi-refractive crystal is not an elliptically polarised ray, but a ray of ordinary light having identical characters on every side. We are thus led to inquire how far the constancy of character of the periodic changes at points in the same ray has really been established by experiment.

In fact, the annihilation-effect (p. 286) of two rays of identical character has only been established for a transference of one of the rays through a distance of at most 50,000 wave-lengths: the wave-length in air for sodium-light being nearly $\frac{3}{5000}$ millimetres, the above distance is nearly 30 millimetres or about one inch: as light is transmitted through air at the rate of 186,000 miles a second, a distance of one inch corresponds to the lapse of only $\frac{1}{11,784,960,000}$ th part of a second.

The discrepancy disappears if a ray is assumed to consist of a series of independent sets of waves of the same length.

10. For the sake of a numerical example, let us imagine that two given rays are absolutely identical in character; that each ray consists of a series of sections; that each section consists of at least a million similar waves, but that the waves of one section are absolutely independent of those of every other, except that they have the same period and are transmitted with the same velocity.

Let the constant sections of one ray be $A_1B_1\ B_1C_1\ C_1D_1 \ldots\ldots Y_1Z_1$, and the identical sections of the other ray be $A_2B_2\ B_2C_2\ C_2D_2 \ldots\ldots Y_2Z_2$: consider the resultant effect of transmitting both heterogeneous rays simultaneously along the same line.

(1.) If the initial points A_1 A_2 coincide, the vibrations are in unison at every point of every section, notwithstanding the heterogeneity of each ray.

(2.) If the ray $A_2 \ldots\ldots Z_2$ be moved parallel to itself along its own direction through the distance $\frac{\lambda}{2}$, the two rays will annihilate each other at all points where identical sections are superposed, but will in general fail to do so in the regions where different sections overlap; that is, for a

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distance $\frac{\lambda}{2}$ at the end of every section. Hence at any given point there will be annihilation while at least 999,999½ waves pass by, and more or less unison while half a wave is passing the same point.

(8.) In the same way, if the ray A_2.....Z_2 be moved parallel to itself along its own direction through the distance 50,000½ wave-lengths, the two rays will still annihilate each other at all points where identical sections are superposed, but will in general fail to do so in the regions where different sections overlap; that is, for a distance 50,000½ wave-lengths at the end of each section. Hence, at any given point, there will be complete annihilation while at least 949,999½ waves pass by, and more or less unison while 50,000½ waves are passing the same point: in other words, instead of complete annihilation, there is more or less light during at most $\frac{1}{20}$th part of the time: the light will be apparently continuous, but its intensity will not exceed the $\frac{1}{20}$th part of the maximum joint effect of the two rays. The variability of the periodic character will thus account for the appreciable diminution of the interference-effect when one of the rays is moved parallel to itself through a considerable number of wave-lengths.

In the following pages we shall only need to consider sets of waves belonging to a single section of constant periodic character, and may thus proceed as if the constancy of character were really a property of the whole ray.

The same assumption accounts for the remarkable fact that rays of the same simple colour, but obtained from different sources, cannot be made to annihilate each other.

11. Hitherto, for simplicity, we have left unmentioned the remarkable fact that rays of light of the same simple colour, whether ordinary or plane-polarised, cannot be made to annihilate each other if they have been derived from different sources. This is quite inexplicable if a ray is assumed to have constancy of periodic character throughout its extent; but it is immediately accounted for by the assumption arrived at in the preceding Article: if a ray consists of a series of *independent* sets of waves, it is physically impossible for two rays from different sources to be identical in their characters.

For a plane-polarised ray, only the amplitudes and phases will differ in the different sets.

We have seen that two plane-polarised rays of constant periodic character throughout would give an elliptically polarised ray of which the ellipses would have a definite magnitude and position dependent on the am-

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plitudes and phases of the component rays: if each of the plane-polarised rays, instead of being of constant periodic character throughout, consists of independent sets of waves, the resultant effect will generally be a rapid succession of elliptically polarised sets, the magnitudes and positions of the ellipses changing as different sections of the plane-polarised rays become superposed; the resultant ray will thus generally be identical in character on all its sides, as far as observation can detect.

Not only is the assumption of variability of periodic character necessary, but a constancy of periodic character could not be physically maintained.

12. A simple pendulum, disturbed and then set free to oscillate under the constant action of gravity, soon comes to rest if allowed to communicate its motion to a surrounding medium: to maintain the oscillations, the pendulum requires to be repeatedly disturbed, and each impulse may change the phase and amplitude, and possibly also the direction of the vibration. In the same way, the vibrations of character at the points of a luminous body must be maintained by the repeated action of something analogous to an impulsive force. It is impossible to imagine that the representative impulse can always have the same magnitude and direction and occur at the particular instant when the vibration is in a particular phase. Hence the vibration must, of almost absolute necessity, be different in its amplitude, phase, or direction, after every impulse.

Further, as already remarked in Art. **6**, any luminous source available for experiment is not a geometrical point, but an area of appreciable magnitude, and the resultant effect at any point is due to the superposition of the effects of rays transmitted from every point of the luminous area: even if it were possible that the vibrations at a single point could be maintained constant in periodic character, it is inconceivable that the constancy of periodic character could be maintained at points belonging to an appreciable area.

A representative force.

13. In the case of a plane-polarised ray of constant character throughout the part considered, the vibratory motion of the representative point p is thus the same for all points P in the line of transmission, and only the phase of the vibration differs at different points at a given instant: hence the expression $y = a \sin\frac{2\pi}{\lambda} vt$, which represents the change of state at the time t at the point for which $\frac{2\pi x}{\lambda} - \alpha = 0$, also represents the vibration at any other point of the ray, if we have due regard in every case to the epoch from

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which the time is measured. The general expression for the law of the change at any point of a plane-polarised ray has been deduced on the assumption that the variation of the state with the time is exactly the same as the variation of position of an isochronous pendulum; or, what is the same thing, of a particle of unit mass vibrating in a straight line and attracted towards an origin in the line by a force of which the magnitude is proportional to the distance therefrom. For the velocity u of the attracted particle at the time t being $\frac{dy}{dt}$, the accelerative force at the same instant is $\frac{du}{dt}$ or $\frac{d^2y}{dt^2}$: by hypothesis the force is attractive, and is measured by f^2 times the distance, or by $-f^2y$, where f is a constant quantity: hence $\frac{d^2y}{dt^2} = -f^2y$.

It is easily seen that $y = B\sin(ft + \beta)$, in which B and β are both independent of the time, is a solution of this differential equation: for differentiating once we have $\frac{dy}{dt} = fB\cos(ft+\beta)$, and differentiating a second time $\frac{d^2y}{dt^2} = -f^2B\sin(ft+\beta) = -f^2y$.

If the time be measured from an epoch of passage through the origin, the constant β is zero and the expression becomes $y = B\sin ft$.

Hence in the case of plane-polarised light, the vibratory motion of the representative point p, being expressed by the relation $y = a \sin \frac{2\pi}{\lambda} vt$, is identical with that of a particle of unit mass attracted towards the origin by a force which is measured by $\frac{4\pi^2v^2}{\lambda^2}$ times the distance.

Even if the actual change of state at the point P were an oscillatory rotation of an ethereal particle about a diameter, as suggested by Rankine,[1] the above kinematical representation would still hold: in that case, the direction of the line Pp would represent that of the axis of rotation of the ethereal particle at P, and the distance Pp would represent the angular disturbance at the given instant.

Or again, the real change may be an electro-magnetic disturbance, whatever that may be.

The representative force is dependent on the luminous source.

14. But it will be obvious on reflection that the relation between the

[1] *Philos. Magazine;* 1853, ser. 4, vol. 6, p. 403.

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distance of the ideal particle, and the ideal force which acting upon the ideal particle would cause a vibration isochronous with that of the periodic change involved in the transmission of the given ray of light, is generally independent of the specific properties of the transmitting medium. The ratio being $4\pi^2v^2 : \lambda^2$ depends only on the ratio $\lambda : v$, that is to say on the period of the vibration or the colour of the light. Now *simple* light generally retains its colour after transmission through any number of different media; it is only in fluorescent bodies that the colour of the light or the period of the change suffers alteration: whence we must infer that the period of vibration at any point of a ray, and thus the ratio of the ideal force to the distance, depends in general, not on the specific properties of the medium, but on the period of vibration of the change at the luminous source. The change of colour frequently observed after the passage of light through a medium is really due to the heterogeneity of the colour of the original light, and to the change of relative *intensity* (not period of vibration, or colour) of the component simple rays.

Further analogy with sound.

15. The same is true in the case of sound. Here again the transmission of a simple note causes a periodic change which may be represented algebraically by the same expression $y = a \sin\left\{\frac{2\pi}{\lambda}(vt-x)+\alpha\right\}$, and kinematically by the same to-and-fro motion of a particle attracted to an origin with a force measured by $\frac{4\pi^2v^2}{\lambda^2}$ times the distance: and the constant ratio $4\pi^2v^2 : \lambda^2$ depends only on the period of the vibration or the note of the sound, and thus on the source of the sound, not on the properties of the transmitting medium. But the actual change of state at any point of a line of transmission of sound being known to be generally a to-and-fro motion of a particle of the medium, the ideal particle and its motion may generally be taken to coincide with the real particle and its motion. Hence the magnitude of the representative force which acts on the ideal particle must not be confused with that of the elastic force which is evoked at the same point by the disturbance of the sound-transmitting medium: the representative force depends on the period of vibration at the source; the elastic force evoked by a given displacement depends on the specific properties of the medium: the resultant force acting on the real particle depends, not only on the specific properties of the medium, but on the continued action of the luminous source.

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The representative force in the case of the vibration of an elastic ether of which the effective density depends on the direction of the vibration.

16. To take another example: in the latest hypothesis as to the properties of an elastic luminiferous ether, it is assumed that the actual and effective elasticity of both volume and figure and the actual density of the ether are the same for all directions in a biaxal crystal, but that the effective density varies with the direction of vibration and is related to three mutually perpendicular lines. Hence, if the ether vibrates freely after disturbance parallel to one or other of these lines, the period of vibration will depend on the direction of the disturbance; for, though the effective elasticity is the same for each direction, the effective density, or effective mass to be put in motion, is different: and the ideal force, which acting on an ideal particle of unit mass gives a synchronous representative vibration, will have a different relation to the distance for the three directions of disturbance, although the ethereal elasticity, both actual and effective, is assumed to be really identical for all directions.

A fallacy.

17. We are now in a position to recognise the fallacy of a method which has been used for the derivation of Fresnel's wave-surface from the properties of an incompressible elastic ether. It is first proved that the elastic force evoked by a unit displacement along a line OP, which is the radius vector of a certain ellipsoid, if resolved along the direction of displacement OP, is $\frac{1}{OP^2}$: that if OP is an axis of a section of the ellipsoid, the other component is perpendicular not merely to OP but also to the plane of the section: that if the section has the direction of the wave-front, the second component is without effect owing to the incompressibility of the ether: that the effective elastic force for unit displacement is thus $\frac{1}{OP^2}$. It is then tacitly assumed that the effective elastic force is identical with the above representative force (which is measured by $\frac{4\pi^2v^2}{\lambda^2}$ times the distance): hence it is inferred that $\frac{4\pi^2v^2}{\lambda^2} = \frac{1}{OP^2}$. It is next wrongly assumed that *the wave-length* λ *is always the same for rays of the same colour transmitted in the same medium*, and that λ in the above relation is thus a constant: whence it is concluded that the velocity varies inversely as OP. That the proof is fallacious is clear from the last Article, in which it has been shown that in the representative vibration the relation of the ideal force

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to the ideal distance is independent of the specific properties of the medium and depends on the luminous source. Indeed the assumption of the constancy of λ is inconsistent with the conclusion, namely that v differs with the direction of vibration; it is obvious that the period $\frac{\lambda}{v}$ and the wave-length λ cannot be both constant if v be variable: the colour really depends on the *period of vibration*, not solely on the wave-length.

Fresnel himself proceeded in a different way, and assumed a relation founded on the analogy of a line of vibrating ethereal particles to a vibrating string.

In general, if a plane-polarised ray is transmissible in a given direction, the plane of polarisation can have at most two different directions.

18. We have seen (Art. 8) that if two plane-polarised rays of the same wave-length can be transmitted along the same line with the same velocity but with different positions of the plane of polarisation, they may be identical in effect with a single plane-polarised ray transmitted along the line with the same velocity but with an intermediate position of the plane of polarisation; the direction of the latter being determined by the ratio of the amplitudes of vibration of the component rays: conversely, the effect of a single ray of given plane of polarisation and simple colour is identical with that of two rays of the same simple colour transmitted along the same line with the same velocity, and with their planes of polarisation in any assigned positions.

Now a plane-polarised ray can be transmitted along the line of intersection of two planes of physical symmetry of the medium, for the planes of symmetry of the plane-polarised ray and the planes of symmetry of the medium may be taken to coincide: but the velocity of the ray will depend upon the position of the plane of polarisation, if the physical relations of the medium relative to the two planes of symmetry are different. If the latter be the case, as for instance when the line is an axis of symmetry of an ortho-rhombic crystal, no ray having a plane of polarisation oblique to the symmetral planes of the crystal can be transmitted along it: for such a ray, if transmissible, would be kinematically equivalent to two rays transmitted along the line with the *same* velocity, each having its plane of polarisation coincident with a different plane of symmetry; two rays can be actually transmitted with these positions of the plane of polarisation, but that their velocity should be equal is in general physically impossible.

In exactly the same way it follows that if along any line, whether an

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axis of symmetry or not, a plane-polarised ray can be transmitted with its plane of polarisation in two different directions but with different velocities in the two cases, a third position of the plane of polarisation is physically impossible.

The refraction of the medium cannot be higher than double.

19. Hence, for a given direction of transmission in such a medium, a plane-polarised ray cannot have more than two different velocities: and the medium cannot present more than double refraction; for, according to the undulatory theory, whatever the nature of the physical change, the direction of the refracted ray is dependent upon its velocity.

Degree of the equation of the ray-surface.

20. A diameter of the ray-surface for such a medium will thus intersect the surface in at most four real points, two on each side of the origin; and the equation of the ray-surface cannot be of a degree higher than the fourth, if it be granted that the above method of proof excludes the existence of imaginary velocities and imaginary points of intersection of a real line with the surface.

In fact, even if there be two imaginary positions of the plane of polarisation for a given real direction of ray-transmission, the imaginary velocities must be in general unequal, since the two planes will be differently related to the crystal and will thus correspond to different crystalline properties, whether real or imaginary. But even if the planes of polarisation be imaginary, the *difference* of the imaginary velocities of the two plane-polarised rays prevents the resultant effect from being that of a single plane-polarised ray with an imaginary plane of polarisation (Art. 8*b*).

The transmissibility of even a single plane-polarised ray is not a physical necessity; but if one position of a plane of polarisation be possible, there is a second at right angles with the first.

21. We may remark that it is not a physical necessity that a plane-polarised ray should be transmissible at all: a plane-polarised ray cannot be transmitted, for instance, along the morphological axis of a crystal of quartz.

As a plane-polarised ray is symmetrical to two planes, the plane of polarisation and the transverse plane, it would seem that if the characters of a crystal admit of one symmetral plane of the ray having a given position, they must admit of the other symmetral plane having the same position: in other words, for a given direction of transmission, if there is

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one possible position of the plane of polarisation, there is a second at right angles to the first. The same result is later arrived at in another way and the positions of the perpendicular planes are determined (Art. 40*c*).

Transmission of a ray along an axis of tetragonal or hexagonal symmetry.

22. On the other hand, the morphological axis of a tetragonal or hexagonal crystal is the intersection of two or more symmetral planes for which the physical relations are identical: hence along such a line it is physically possible to transmit two rays having the same velocity and different planes of polarisation, and thus having a resultant effect identical with that of a single plane-polarised ray. The amplitudes of the component rays being arbitrary may be so adjusted that the equivalent single plane-polarised ray has any plane of polarisation whatever: and it follows that along the morphological axis of a given tetragonal or hexagonal crystal a ray may be transmitted with any direction of the plane of polarisation, but in each case with the same velocity.

The velocity-factor.

23. The velocity of transmission of a plane-polarised ray of given colour is found to depend on the properties of the medium: since the vibration is in only a single direction, we may assume that the velocity of transmission corresponding to a given direction of vibration depends *solely* on the properties of the medium relative to the direction of the vibration. To avoid confusion of ideas, let the action of the medium in so far as it affects the velocity of a ray of given direction of vibration be said to be due to a *velocity-factor*; the magnitude of the factor depending on the properties of the medium for the direction of the periodic change or vibration.

The velocity-factor is necessarily the same for all directions perpendicular to an axis of tetragonal or hexagonal symmetry.

24. We have shown, from principles of mere symmetry of the medium and superposition of changes, without regard to their physical character, that along the morphological axis of a tetragonal or hexagonal crystal a ray is transmissible with the plane of polarisation in any azimuth whatever, and that the velocity of transmission of the ray is always the same: hence, for all directions of vibration perpendicular to the morphological axis of a uniaxal crystal, the velocity-factor has the same magnitude. It follows that the symmetry of the velocity-factor, at any rate for directions of

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rectilinear vibration lying in a plane perpendicular to the tetragonal or hexagonal axis of symmetry, is of a higher order than that of the morphological development.

The corresponding geometrical character is worthy of remark, namely, that in a parallelepipedal system of points every plane of the system passing through an axis of tetragonal or hexagonal symmetry is a plane of symmetry for the planes and lines, though not for the points, of the system: the symmetry of the system relative to such a plane being in general "symmetry of aspect," and not absolute.[1]

Transmission of a ray in a direction lying in a plane of physical symmetry but oblique to an axis of tetragonal or hexagonal symmetry.

25. Consider the case of a ray transmitted in one of the planes of symmetry S of a tetragonal crystal, but in a direction oblique to the morphological axis. Either plane of symmetry of the plane-polarised ray may be taken to coincide with the plane of symmetry S of the crystal: this is confirmed by experiment, for these directions of the planes of polarisation of a ray are found to be physically possible. But if the plane of polarisation of the ray is coincident with the plane of symmetry S of the crystal, and the vibration is assumed to be perpendicular to the plane of polarisation, the vibration is perpendicular to the morphological axis whatever the position of the ray in the plane: hence, according to the preceding Article, the velocity-factor, and therefore the velocity of the ray, will be the same for all ray-directions in this plane, and one curve of intersection of the ray-surface with the plane of symmetry S of the crystal will be a circle. On the other hand, if the plane of polarisation of the ray is normal to the plane of symmetry S of the crystal, the vibration will be in the same plane of symmetry S and in a direction oblique to the morphological axis: the physical characters belonging to the direction of the vibration, including the velocity-factor, will thus vary with the direction of the ray, and the velocity-curve corresponding to those rays of which the plane of polarisation is normal to the symmetral plane S of the crystal will not be circular: the curve will be symmetrical, however, both to the morphological axis and a line perpendicular to it, for they are directions with respect to which all the characters of the crystal are symmetrical. Further, the second curve will touch the first at its points of intersection with the morphological axis: for the two directions perpendicular to that line, and lying respectively in and perpendicular to the plane of symmetry S, are by

[1] H. J. S. Smith; *Philosophical Magazine*, 1877, ser. 5, vol. 4, p. 18.

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hypothesis similar in all their relations, and correspond therefore to the same velocity-factor; hence both curves meet on the morphological axis, and therefore touch each other, for the morphological axis divides each curve symmetrically.

But since the equation of the ray-surface has been shown to be of a degree not higher than the fourth, and the equation of one curve of intersection, a circle, is of the second degree, that of the other curve will likewise be of the second degree, and therefore represent an ellipse—for the curve is closed and has unequal diameters. This result agrees with the experimental discovery made by Huygens.

Transmission of rays along the axes of symmetry of an ortho-rhombic crystal.

26. Take next the case of an ortho-rhombic crystal. In the first place, as shown in Art. **18**, a ray can be transmitted along any of the axes of symmetry, and have its plane of polarisation coincident with either of the symmetral planes of the crystal which intersect therein. The three axes of symmetry being independent of each other in all their physical relations, the velocity-factors will be independent; and vibrations parallel to the several axes will thus in general correspond to different velocities of transmission. Let the velocity corresponding to an axis OX, OY, or OZ, *considered as a direction of vibration*, be denoted by a, b, or c respectively: then two rays are transmissible along OX with velocities b and c, and planes of polarisation normal to OY and OZ respectively: two rays are transmissible along OY with velocities c and a, and planes of polarisation normal to OZ and OX respectively: two rays are transmissible along OZ with velocities a and b, and planes of polarisation normal to OX and OY respectively.

Transmission of rays in a symmetral plane of an ortho-rhombic crystal.

27. Again, as far as directions lying in the plane of symmetry OXZ are concerned, there is no essential difference between an ortho-rhombic and a tetragonal crystal, if OZ is the morphological axis of the latter. The essential difference between two such crystals is that in one of them (the ortho-rhombic) the third axis of symmetry OY is independent of OX in its physical relations, and in the other (the tetragonal) is identical therewith. Hence we may infer that in the symmetral plane OXZ of an ortho-rhombic crystal, a ray is transmissible in any direction with its plane of polarisation either coincident with or perpendicular to that plane. Also, as in the case of a tetragonal crystal, the intersection of the ray-

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surface with the symmetral plane will be a circle and a concentric ellipse: but, in the ortho-rhombic crystal, the circle and ellipse will be independent of each other in magnitude, since the velocity-factor for the direction of vibration OY is independent of that for the direction of vibration OX.

Intersections of the ray-surface with the symmetral planes of an ortho-rhombic crystal.

28. The intersections of the ray-surface with the axial planes OYZ, OZX, OXY of an ortho-rhombic crystal will thus be given by the following equations:—

$$(y^2+z^2-a^2)(b^2y^2+c^2z^2-b^2c^2)=0,$$
$$(z^2+x^2-b^2)(c^2z^2+a^2x^2-c^2a^2)=0,$$
$$(x^2+y^2-c^2)(a^2x^2+b^2y^2-a^2b^2)=0.$$

General equation of the ray-surface for an ortho-rhombic crystal.

29. The equation of the ray-surface itself must be of the form

$$(y^2+z^2-a^2)(b^2y^2+c^2z^2-b^2c^2)+x\,\phi(xyz)=0,$$

since it reduces to the first expression when x is made zero. But according to Art. **20** the quantity $x\,\phi(xyz)$ cannot consist of terms of degrees higher than the fourth: further, the surface being symmetrical to the axial planes, its equation can only involve even powers of $x\,y\,z$: hence the only terms which can enter the expression $x\,\phi(xyz)$ are x^4, z^2x^2, x^2y^2 and x^2.

The general equation is thus of the form

$$(y^2+z^2-a^2)(b^2y^2+c^2z^2-b^2c^2)+Ax^4+Bz^2x^2+Cx^2y^2+Dx^2=0;$$

or, multiplying out,

$$Ax^4+b^2y^4+c^2z^4+(b^2+c^2)y^2z^2+Bz^2x^2+Cx^2y^2+Dx^2-b^2(c^2+a^2)y^2$$
$$-c^2(a^2+b^2)z^2+a^2b^2c^2=0.$$

Also, it is evident from the equations of the curves of intersection with the three axial planes that xyz and abc are simultaneously cyclically interchangeable (Art. **28**); hence

$$A=a^2;\quad B=c^2+a^2;\quad C=a^2+b^2;\quad D=-a^2(b^2+c^2).$$

Substituting these values, the equation becomes

$$(x^2+y^2+z^2)(a^2x^2+b^2y^2+c^2z^2)-a^2(b^2+c^2)x^2-b^2(c^2+a^2)y^2-c^2(a^2+b^2)z^2+a^2b^2c^2=0$$

or, multiplying by r^2,

$$r^4(a^2x^2+b^2y^2+c^2z^2)-r^2\{a^2(b^2+c^2)x^2+b^2(c^2+a^2)y^2+c^2(a^2+b^2)z^2\}+a^2b^2c^2(x^2+y^2+z^2)=0$$

or $a^2x^2(r^2-b^2)(r^2-c^2)+b^2y^2(r^2-c^2)(r^2-a^2)+c^2z^2(r^2-a^2)(r^2-b^2)=0$

or $$\frac{a^2x^2}{r^2-a^2}+\frac{b^2y^2}{r^2-b^2}+\frac{c^2z^2}{r^2-c^2}=0:$$

which is Fresnel's equation of the ray-surface.

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The ray-surface for a mono-symmetric or anorthic crystal.

30. (*a*) Next consider the case of a crystal which admits of the transmission of a ray of plane-polarised light in any direction, but presents only a single plane of geometrical and physical symmetry, and thus belongs to the mono-symmetric system: let the normal of the plane of symmetry be OY.

Since, from a purely geometrical point of view, a mono-symmetric crystal may be regarded as a homographic transformation of an ortho-rhombic crystal, it first suggests itself that the ray-surface for a mono-symmetric crystal may be such as would result from a corresponding transformation of the ray-surface for an ortho-rhombic crystal. That the analogy is imperfect, however, is evident from the fact that there is no corresponding distortion of the planes of polarisation; whatever the direction of ray-transmission within the mono-symmetric crystal, the planes of polarisation of the two transmissible rays are perpendicular to each other (Art. **21**).

1. As in Art. **27**, any ray whatever lying in the plane of symmetry can have that plane for either its plane of polarisation or its transverse plane: hence, exactly in the same way as before, it follows that the plane of symmetry intersects the ray-surface in two curves, the one a circle, the other a concentric ellipse: the former corresponding to the rays which have the symmetral plane for the plane of polarisation, the latter to the rays for which the plane of symmetry is the transverse plane. If OX OZ be the axes of the ellipse, a ray transmitted along OX will thus have its representative vibrations parallel to either OY or OZ; and a ray transmitted along OZ will have its vibrations parallel to either OY or OX.

2. A ray transmissible along the line OY can have its plane of polarisation in only one or other of two directions of which the normals are perpendicular both to each other and to the line OY (Art. **21**).

3. Since the elliptic and circular sections of the ray-surface made by the plane XOZ are both of them symmetrical to the lines OX OZ, while the plane XOZ is a plane of general physical symmetry of the crystal, and its normal OY is an axis of general symmetry of diagonal type, we may reasonably assume that *for this particular property* (so long as there is no variation of colour or temperature) the planes YOX YOZ are themselves planes of symmetry of the crystal; in which case, the lines OX OZ will be the directions of vibration of the two rays transmissible along the axis OY.

4. For the given colour and temperature, the circumstances are identical, for this particular property, with those of an ortho-rhombic crystal having OX OY OZ for axes of symmetry: and the ray-surface

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will thus for a mono-symmetric crystal have the same general form as for an ortho-rhombic one.

(*b*) The general form of the ray-surface, being quite unaffected by the degradation of the symmetry from the ortho-rhombic to the mono-symmetric type, is clearly independent of the type of symmetry altogether: the general form will therefore be the same even for an anorthic crystal.

The difference in the type of symmetry thus affects, not the general form of the ray-surface, but only the constancy of the directions and relative lengths of the axes of the surface for different colours and temperatures. An axis of general symmetry of the crystal is necessarily an axis of symmetry of the ray-surface whatever the colour of the light or the temperature of the crystal (p. 297).

The form of the ray-surface is independent of the physical character of the periodic change.

31. The rigorous accuracy of the form assigned to the ray-surface by Fresnel is thus a necessary consequence of the general features of perpendicularly transverse undulations, independently of the physical character of the change.

And although, as in the case of an incompressible elastic ether with effective rigidity dependent upon the direction of vibration, the same form of ray-surface may result notwithstanding the obliquity of the transverse vibration, this is not generally true. The form of the ray-surface which follows, for example, from a version of the elastic theory of double refraction suggested by Rankine and further developed by Lord Rayleigh is different from that of Fresnel, and only gives the latter as a first approximation. That version, according to which the ether is incompressible and has an effective density dependent on the direction of vibration, involves the general obliquity of the latter to the direction of transmission.[1]

In fact, whatever the degree of symmetry of the characters of a plane-polarised ray as transmitted within a medium, the above form of ray-surface will result from any hypothesis which has for necessary consequence that if one plane-polarised ray is transmissible in a given direction, a second plane-polarised ray is transmissible in the same direction with a different velocity and has its plane of polarisation perpendicular to that of the first.

It may be remarked that in the above reasoning no assumption as to the molecular constitution of the ether has been necessary.

[1] *Philosophical Magazine;* 1851, ser. 4, vol. 1, p. 441; 1888, ser. 5, vol. 26, pp. 525, 527.

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Resilience.

32. It was explained in Art. **14** that the period of the change at any point of a ray of light depends in general on the period of the change at the luminous source, and not on the specific properties of the medium; but the latter may conceivably affect some or all of the remaining characters of the ray, namely, amplitude and direction of vibration, velocity and direction of transmission through the medium. The property by virtue of which a periodic change of any kind is transmissible through a medium may be denoted by the general term *resilience*: we may imagine that a disturbance at any point of the medium evokes an opposing resilience of which the magnitude increases with the amount of the disturbance. Optical resilience, in so far as it affects only the velocity of transmission of a periodic change having a given direction, is identical with the velocity-factor for that direction, mentioned in Art. **23**. When the periodic change is a vibratory motion such as follows the removal of a compressing or distorting force, resilience is identical with elasticity of volume or figure.

From this point of view, the periodic change at any point of a ray of plane-polarised light may be treated as a resultant effect of two forces; the one an *initiatory* linear force periodic in its variations, and having a period identical with that of the luminous source; the other a *secondary* force or a resilience, evoked by the disturbance produced by the initiatory force.

Free and forced vibrations.

33. The periodic change at a point of a ray of light is a *forced* vibration, resulting from the continued action of the luminous source: it differs from a *free* vibration, such as would be produced by resilience alone if the luminous source were removed while the medium is in a state of disturbance.

A simple case of free vibration.

34. In the simplest possible case of free vibration of a character of a medium, we may imagine that the disturbance at the point is of such a kind that at any instant it can be represented by the length and direction of a straight line y drawn from an ideal particle of unit mass to the point, and that the resilience of the medium can be represented by an ideal force acting in the line of disturbance, tending to diminish the disturbance, and proportional in magnitude to the disturbance itself, the proportion being independent of direction: such a medium may be said to be *isotropically* resilient for the given character.

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As in Art. 13 we may write

$$\frac{d^2y}{dt^2} = -f^2y,$$

where f is independent of the time and depends on the properties of the medium.

A solution of this equation is $y = B\sin(ft+\beta)$, where B and β are constants: the expression represents a vibration of which the period is $\frac{2\pi}{f}$, since any value of y recurs when t is increased by an integral multiple of that quantity.

As already pointed out, such a mode of representation is still possible, even when the actual change is an oscillatory rotation of an ethereal particle (Art. 13).

A simple case of forced vibration.

35. But suppose that in the above medium the vibration at the point is not free but forced, and that the initiatory force is a periodic one related to the time in the same way as the disturbance at a point of a plane-polarised ray of simple colour; the initiatory force can in such case be represented by an expression of the form $S\sin st$, where S and s are constants, and the latter depends only on the period of vibration of the luminous source. As before, the ideal resultant force acting on the ideal particle of unit mass is $\frac{d^2y}{dt^2}$, and is due to the superposition of the initiatory force $S\sin st$ and the resilience $-f^2y$: hence $\frac{d^2y}{dt^2} = S\sin st - f^2y$.

It is easily seen that $y = B\sin st$ is a solution of this differential equation: for differentiating, we get first $\frac{dy}{dt} = Bs\cos st$, and next $\frac{d^2y}{dt^2} = -Bs^2\sin st$: substituting in the above equation, and dividing by $\sin st$, we get $B = \frac{S}{f^2-s^2}$: and thus $y = \frac{S}{f^2-s^2}\sin st$. Hence the resilience affects merely the amplitude, not the period or general character of the vibration at the point.

The resilience being $-f^2y$ has likewise the same period as the initiatory force.

Transmission of a simple forced vibration in an isotropically resilient medium.

36. If a luminous source is in a state of periodic vibration represented

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kinematically by the linear motion of a particle attracted to an origin by a force proportional to the distance, and is surrounded by a medium such that the resilience is represented by a force acting in the line of disturbance and proportional to it in magnitude, the changes transmitted through the medium along a given direction perpendicular to that of the vibration may thus be expected to be always in the same plane and have the same period; no resilient force oblique to the plane containing the direction of ray-transmission and the direction of vibration of the luminous source is evoked by the disturbance: in any direction of an isotropically resilient medium, a plane-polarised ray, if transmissible at all, may thus be transmitted with any azimuth of plane of polarisation whatever.

A more general case of free vibration of an œlotropically resilient medium.

37. As a more general case, we may imagine that in a crystalline medium there are three directions, not co-planar, inclined obliquely or perpendicularly to each other, for each of which a disturbance evokes a resilience which in its effects is represented by an ideal force, contrary and proportional to the disturbance, acting on an ideal particle of unit mass; the relation of the ideal representative force to the distance of an ideal attracted particle of unit mass being, however, like most other physical characters, different for the three directions: the latter may be termed *axes of optical resilience.*

That such a representation is possible, even in an elastic ether of which the elasticity is the same in all directions, has already been pointed out in Art. **16**: for if the effective density depends on the direction of vibration, the period of a free vibration will also vary with the direction, since although the real accelerative force has the same constant relation to the distance it will have a different effective mass to keep in motion.

When it is desirable to emphasise the fact that the resilient force under consideration is the ideal force which would produce an analogous to-and-fro motion of a particle of unit mass and not the statical force necessary to the maintenance of a given state of disturbance, we may conveniently distinguish it as *vibrational resilience.* If the three constants of vibrational resilience be respectively $e^2 f^2 g^2$, and $x\ y\ z$ be the distances which represent the disturbances parallel to the respective axes at any time t, we have for a free vibration due to a disturbance along each of the axes

$$\frac{d^2x}{dt^2} = -e^2x\,;\ \frac{d^2y}{dt^2} = -f^2y\,;\ \frac{d^2z}{dt^2} = -g^2z:$$

whence, in the same way as before,

$$x = A\sin(et+\alpha)\,;\ y = B\sin(ft+\beta)\,;\ z = C\sin(gt+\gamma).$$

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According to the principle of superposition of changes, if the direction of the initial disturbance at the point is inclined to the three axes of resilience, the initial disturbance may be resolved along those directions, and the resultant free vibration is such as would result from the composition of the free vibrations corresponding to the several axial directions. Hence, if the vibration is free, the disturbance at a given instant is determined by the above triad of equations.

Since the ratios $x : y : z$ depend on the time, the motion of the representative particle is not in a straight line passing through the origin. The particle in fact describes a curve in three dimensions, and never passes twice through the same position unless the ratios $e : f : g$ are commensurable.

The quantities $e^2 f^2 g^2$ may be conveniently termed *coefficients of optical vibrational resilience*: and the medium may be said to be *œolotropically* resilient. The coefficients of vibrational resilience are independent of x and t for the same ray, but even with the same medium may conceivably be different for different rays, and thus vary with the period of the change, or in other words, with the colour of the light.

In Art. 42 it is pointed out that obliquity of mutual inclination of the axes of optical resilience is not met with even in mono-symmetric or anorthic crystals.

A more general case of forced vibration of an œolotropically resilient medium.

38. Consider next a forced vibration of a crystalline medium having three dissimilar oblique or rectangular axes of vibrational resilience as before: assume that the initiatory force at any point of a ray may again be represented by an expression of the form $S \sin st$, where s is a constant depending on the period of the change at the luminous source.

If OP be any line passing through an origin O, and OL OM ON, lengths measured along the axes of resilience, be edges of a parallelepiped of which OP is a diagonal, whatever the length OP we have

$$OL = \lambda \cdot OP \quad OM = \mu \cdot OP \quad ON = \nu \cdot OP,$$

where λ μ ν are constants for a given direction of OP.

From the principle of superposition, it follows that the initiatory force $S \sin st$ acting in the line OP can be resolved into three initiatory forces $\lambda S \sin st$ $\mu S \sin st$ $\nu S \sin st$, acting along the axes of x y z respectively.

In exactly the same way as before we have the following expressions for the several vibrations parallel to the respective axes:—

$$x = \frac{\lambda S}{e^2 - s^2} \sin st; \quad y = \frac{\mu S}{f^2 - s^2} \sin st; \quad z = \frac{\nu S}{g^2 - s^2} \sin st;$$

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where the quantities $\lambda\ \mu\ \nu\ e^2 f^2 g^2\ S$ and s are all independent of the time.

Hence the ratios $x : y : z$ are also independent of the time, and the representative particle vibrates in a straight line through the origin.

The period of the resultant vibration is identical with that of the initiatory force, but the direction of the vibration is different. If $\lambda'\ \mu'\ \nu'$ determine the direction of the resultant vibration,

$$\lambda' : \mu' : \nu' = x : y : z = \frac{\lambda}{e^2 - s^2} : \frac{\mu}{f^2 - s^2} : \frac{\nu}{g^2 - s^2}\ .$$

Further, the axial components of the representative resilient force being $-e^2x,\ -f^2y,\ -g^2z$, or

$$-\frac{e^2\lambda S}{e^2 - s^2}\sin st,\quad -\frac{f^2\mu S}{f^2 - s^2}\sin st,\quad -\frac{g^2\nu S}{g^2 - s^2}\sin st,$$

the resultant resilient force will have a direction determined by the ratios

$$\frac{e^2\lambda}{e^2 - s^2} : \frac{f^2\mu}{f^2 - s^2} : \frac{g^2\nu}{g^2 - s^2}\ .$$

Hence the resultant resilient force always acts in the same direction throughout the vibration, but it is inclined to the direction $\lambda\ \mu\ \nu$ of the initiatory force and also to the line of vibration $\lambda'\mu'\nu'$, both of which pass through the origin: further the resultant resilient force has the same period as the initiatory force.

Transmission of a simple forced vibration in an œolotropically resilient medium.

39. In such a medium, therefore, an initiatory linear periodic force having a direction inclined to an axis of resilience and acting at a given point gives rise at that point to a linear periodic vibration in a direction inclined to the initiatory force, and to a resilience of which the resultant effect is represented by a periodic force acting on the ideal particle in a third and constant direction not passing through the given point. Since the periodic change is transmitted through the medium by virtue of the resilience, and action is always equal and contrary to reaction, we should thus expect that along any line of transmission the direction of the periodic change will in general vary from point to point of the ray; and that the transmitted periodic change can only be in a direction lying always in the same plane, if the plane containing the initiatory force and the direction of transmission likewise contains the direction of the resilient force, and therefore also the direction of representative vibration.

Consider, for example, the case of a ray transmissible along an axis OX of an ortho-rhombic crystal: from the symmetry it follows that a plane-

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polarised ray transmitted along OX must have its vibrations parallel to one or other of the dissimilar axes OY OZ, and that for a ray of given simple colour the velocity of transmission will depend on the direction of vibration. If, however, the initiatory force at the initial point of the ray, though perpendicular to OX, is oblique to the axes OY OZ, it may be resolved into two forces, parallel to OY OZ respectively, and each may be regarded as originating a simple plane-polarised ray: the motion of the representative point will be the resultant of the motions belonging to each ray, and will thus be continually changing its direction as the disturbance is transmitted along OX.

Case of an ortho-rhombic crystal.

40. (*a.*) *Direction of the resultant vibrational resilience for a given disturbance.* For simplicity, let the crystalline medium present three mutually perpendicular but dissimilar symmetral planes, and thus belong to the ortho-rhombic system: the axes of resilience necessarily coincide with the crystallographic axes, the lines of intersection of the symmetral planes. Let $X\,Y\,Z$ be the components, parallel to the axes of co-ordinates, of the representative resilient force corresponding to a disturbance defined by the co-ordinates $x'\ y'\ z'$: then

$$X=-e^2x';\ Y=-f^2y';\ Z=-g^2z'.$$

The direction-cosines of the resultant resilience F are in the ratios

$$X:\ Y:\ Z:\ \text{or}\ e^2x':f^2y':g^2z'.$$

But if an ellipsoid $e^2x^2+f^2y^2+g^2z^2=1$ be of such dimensions that it passes through the point P $(x'y'z')$, the direction-cosines of PG the normal of the ellipsoid at the point $x'y'z'$ are likewise in the ratios $e^2x' : f^2y' : g^2z'$ (Fig. 19).

Hence the resultant resilient force due to a disturbance OP acts in the direction PG of the normal of the ellipsoid $e^2x^2+f^2y^2+g^2z^2=1$ at the point P $(x'y'z')$ lying on its surface.

(*b.*) *Direction of transmission of a plane-polarised ray of which the direction of the plane of polarisation is given.*

If O be the centre of the ellipsoid and OP the representative direction of vibration, the initiatory force must also lie in the plane OPG which contains the direction of vibration and the secondary force: further, the direction of transmission must lie in the same plane (Art. **39**). The vibration being always perpendicularly transversal to the direction of transmission, the ray Or corresponding to the vibration OP is thus in the plane OPG and perpendicular to OP (Fig. 19).

(*c.*) *The planes of polarisation for a given direction of ray are perpen-*

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dicular to each other, and have directions which can be defined by means of an ellipsoid.

It has already been proved (Section IV, Art. 24) that if OP be a central radius vector of an ellipsoid, and PG the normal of the ellipsoid at P, the line OP is an axis of the section of the ellipsoid by a plane through OP perpendicular to the plane OPG; for a given direction of ray Or there are thus two possible directions of vibration OP_1 OP_2, which can be transmitted without change of plane, and they are the axes of the section of the ellipsoid by a plane to which the ray Or is normal. Hence the planes of polarisation corresponding to a given direction of ray are perpendicular to each other and are determined by the above geometrical construction.

(*d.*) *Magnitudes of the total and effective vibrational resilience for a given disturbance.*

If F be the resultant resilience, $F^2 = X^2 + Y^2 + Z^2 = e^4x'^2 + f^4y'^2 + g^4z'^2$.

But if OM (Fig. 19) be the central normal to the tangent plane at P $(x'y'z')$,

$$\frac{1}{OM^2} = e^4x'^2 + f^4y'^2 + g^4z'^2. \quad \text{(Sec. IV, Art. 4).}$$

Hence the resultant resilience F is measured by $\frac{1}{OM}$.

The resilience being in the direction PG, and the actual vibration in the direction PO, the effective resilience is $F \cos OPG$

$$= F\frac{OM}{OP} = \frac{1}{OP}.$$

This corresponds to a disturbance of magnitude OP: hence the effective resilience for a unit disturbance in the direction OP is $\frac{1}{OP^2}$.

(*e.*) *Relation between the effective vibrational resilience and the velocity of transmission.*

In the development of his theory of Double Refraction, Fresnel was compelled to make an assumption as to the relation between the effective elastic force and the velocity of normal propagation of the corresponding wave, and supported his assumption by reference to the analogy of a vibrating string.

In the preceding Articles, all the forces are purely representative, and the assumptions and reasoning founded thereon are really independent of the physical character of the change. But it is clear that the velocity of transmission must depend on the physical character of the periodic change, and that it is impossible to proceed farther and deduce the absolute velocity

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of transmission without some assumption involving the nature of the change and the constitution of the ether. All that we have been able to suggest hitherto is that the velocity is in some way dependent on the characters of the medium relative to the direction of the vibration, and these characters have been collectively expressed by the term velocity-factor: in other words, it was suggested that the velocities of the two rays transmissible in the direction Or are determined by some function of the directions of vibration OP_1 OP_2, and thus by some function of the lengths OP_1 OP_2, for the length of a radius vector of an ellipsoid is determined by the direction. But we have also shown (Art. **29**) that, without any assumption as to the real nature of the change, it is possible to determine the velocities $r_1 r_2$, of the two rays transmissible in a given direction, in terms of $a\,b\,c$, the velocities corresponding to vibrations in the directions of the principal axes: hence the velocity r of transmission along Or is necessarily so related to OP, an axis of the section of the ellipsoid $e^2x^2+f^2y^2+g^2z^2=1$ by the plane perpendicular to Or, that the equation

$$\frac{a^2x^2}{r^2-a^2}+\frac{b^2y^2}{r^2-b^2}+\frac{c^2z^2}{r^2-c^2}=0$$

represents the ray-surface. There is only one relation between r and OP which leads to this form of ray-surface, namely $r=OP$: we are thus compelled to infer that the velocity of transmission of a ray is directly proportional to that radius vector OP of the above ellipsoid $e^2x^2+f^2y^2+g^2z^2=1$, which has the same direction as the vibrations of the ray: from Art. **40***d* it follows that the same relation is expressed by the statement that the ray-velocity is *inversely* proportional to the square root of the effective resilience for unit disturbance in the direction of vibration.

It follows from the above relation that:—

If a line Or is perpendicular to a central section of the ellipsoid $e^2x^2+f^2y^2+g^2z^2=1$, and OP_1 OP_2 are the axes of the section, a plane-polarised ray can be transmitted along Or, having OP_1 or OP_2 for the normal of its plane of polarisation and a velocity of transmission measured by OP_1 or OP_2 respectively.

That this relation is consistent with the form of the ray-surface arrived at in Art. **29** may be proved as follows:—

(*f.*) *Transformation of the above construction.*

From O draw OM perpendicular to the plane which touches the ellipsoid $e^2x^2+f^2y^2+g^2z^2=1$ at the point P, and let M be the foot of the perpendicular: produce OM to R, making $OR\cdot OM=1$.

(1.) First—find the locus of the points R when P takes all positions on the ellipsoid $e^2x^2+f^2y^2+g^2z^2=1$.

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Let $x'y'z'$ be the co-ordinates of P (Fig. 19); the tangent plane at P is $e^2x'x+f^2y'y+g^2z'z=1$: hence, as in Art. 40*d*,

$$\frac{1}{OM^2}=e^4x'^2+f^4y'^2+g^4z'^2.$$

If $\xi\ \eta\ \zeta$ be the co-ordinates of the point R, we have $\frac{\xi}{e^2x'}=\frac{\eta}{f^2y'}=\frac{\zeta}{g^2z'}$; for, by construction, the line OMR is perpendicular to the tangent plane $e^2x'x+f^2y'y+g^2z'z=1$.

Each of these fractions is equal to $\frac{\sqrt{(\xi^2+\eta^2+\zeta^2)}}{\sqrt{(e^4x'^2+f^4y'^2+g^4z'^2)}}$; that is $OR\cdot OM$, or unity.

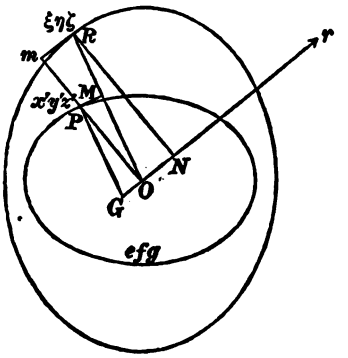

FIG. 19.

We thus have $\frac{\xi}{e}=ex';\ \frac{\eta}{f}=fy';\ \frac{\zeta}{g}=gz'$:

whence, since $e^2x'^2+f^2y'^2+g^2z'^2=1$,

it follows that $$\frac{\xi^2}{e^2}+\frac{\eta^2}{f^2}+\frac{\zeta^2}{g^2}=1.$$

This is the equation of the locus of the points R, and represents an ellipsoid with the same symmetral planes as $e^2x^2+f^2y^2+g^2z^2=1$, but with semi-axes $e\ f\ g$ instead of $\frac{1}{e}\ \frac{1}{f}\ \frac{1}{g}$.

(2.) The equation of the plane which touches the ellipsoid $\frac{\xi^2}{e^2}+\frac{\eta^2}{f^2}+\frac{\zeta^2}{g^2}=1$ at the point $R\ (\xi\ \eta\ \zeta)$ is

$$\frac{x\xi}{e^2}+\frac{y\eta}{f^2}+\frac{z\zeta}{g^2}=1.$$

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If Om be the perpendicular on this plane from the origin, the direction-cosines of Om have the ratios $\frac{\xi}{e^2} : \frac{\eta}{f^2} : \frac{\zeta}{g^2}$, or $x' : y' : z'$; hence the line Om passes through the point P.

RN, the normal of the ellipsoid $\frac{\xi^2}{e^2}+\frac{\eta^2}{f^2}+\frac{\zeta^2}{g^2}=1$ at R, is parallel to Om, and will thus intersect the line Or which lies in the plane ORP: if N be the point of intersection, $RN=Om$.

(3.) In the same way as before, since Om is the perpendicular from the origin to the plane $\frac{x\xi}{e^2}+\frac{y\eta}{f^2}+\frac{z\zeta}{g^2}=1$,

$$\frac{1}{RN^2}=\frac{1}{Om^2}=\frac{\xi^2}{e^4}+\frac{\eta^2}{f^4}+\frac{\zeta^2}{g^4}=x'^2+y'^2+z'^2=OP^2.$$

The plane ORN is thus identical with the plane OPG; the normal RN to the ellipsoid at the point R has the same direction as OP and represents the direction of the vibration: $\frac{1}{RN}$ is equal to OP and therefore measures the velocity of transmission.

Hence the relation given above in Art. **40***e* is equivalent to the following:—If Or is the direction of transmission of a ray, the direction of the vibration, or the normal of the plane of polarisation, is normal to the line Or and also to the ellipsoid $\frac{x^2}{e^2}+\frac{y^2}{f^2}+\frac{z^2}{g^2}=1$; its velocity is measured by the *inverse* of the length of this normal intercepted between the ray and the ellipsoid: further the normal of the ellipsoid is perpendicular to the plane of polarisation of the corresponding ray.

It has been proved in Section IV that the ray-surface which follows from this relation is

$$\frac{\frac{1}{e^2}x^2}{r^2-\frac{1}{e^2}}+\frac{\frac{1}{f^2}y^2}{r^2-\frac{1}{f^2}}+\frac{\frac{1}{g^2}z^2}{r^2-\frac{1}{g^2}}=0;$$

it has also been proved (Art. **29**), without any assumption as to the real nature of the periodic change, that the equation of the ray-surface is

$$\frac{a^2x^2}{r^2-a^2}+\frac{b^2y^2}{r^2-b^2}+\frac{c^2z^2}{r^2-c^2}=0:$$

the results are consistent with each other if $e=\frac{1}{a}$, $f=\frac{1}{b}$, $g=\frac{1}{c}$; the

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ellipsoid $\frac{x^2}{e^2}+\frac{y^2}{f^2}+\frac{z^2}{g^2}=1$ is identical with the optical indicatrix

$$a^2x^2+b^2y^2+c^2z^2=1.$$

Comparison with Fresnel's elastic forces.

41. (α.) If $a\ b\ c$ are the velocities of transmission of those rays of which the vibrations are parallel to the axes of $x\ y\ z$ respectively, Fresnel's method of derivation requires the elastic forces evoked by unit displacements along the axes to be taken as $a^2\ b^2\ c^2$ respectively: according to the above method, the ideal forces, which by their action on an ideal particle of unit mass would produce vibrations synchronous with those of the medium, will be measured by $e^2f^2g^2$ or $\frac{1}{a^2}\frac{1}{b^2}\frac{1}{c^2}$ for unit displacements of the ideal particle along those directions.

(β.) In Fresnel's method, the evoked elastic force normal to the direction of vibration of a real particle of ether is regarded as of no effect owing to the incompressibility of the medium: in the above method no assumption is made as to the compressibility or incompressibility of the medium, but that component of the representative resilient force which is normal to the direction of vibration of an ideal particle is regarded as balanced by an equal component of the representative initiatory force at the same point of the ray.

Case of a mono-symmetric or anorthic crystal.

42. If the medium could present three dissimilar axes of optical resilience obliquely inclined to each other, it would follow as before that the axial components of the resilient force, corresponding to a disturbance defined by the co-ordinates $x'y'z'$, would be

$$X=-e^2x'\ ;\ Y=-f^2y'\ ;\ Z=-g^2z'\ :$$

but the resultant resilient force F would no longer act along the normal to the ellipsoid $e^2x^2\mp f^2y^2+g^2z^2=1$, and the planes of polarisation of the rays transmissible along a given direction would no longer be at right angles to each other.

As such a character is not presented by any crystal which has been examined, we may infer that in all crystalline media the axes of optical resilience for a given colour and temperature are always mutually perpendicular, and that the symmetry of the crystal merely affects the directions of the triads of perpendicular lines and the ratios of the corresponding coefficients of optical resilience.

An unsatisfactory variation of Fresnel's method.

43. At first sight it would seem that the following would be a satisfac-

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tory and more simple mode of altering Fresnel's assumptions and reasoning so as to accord with the recent conclusion that the vibration is parallel, not to the radius vector RO, but to the normal RN of the ellipsoid $a^2x^2+b^2y^2+c^2z^2=1$.

Let $-a^2\xi, -b^2\eta, -c^2\zeta$, be the resolved axial components of the elastic force on a particle, due to a displacement from the centre O to the point R $(\xi\ \eta\ \zeta)$ lying on the surface of the ellipsoid $a^2x^2+b^2y^2+c^2z^2=1$. It may be shown as above that the elastic force acting on the particle when at R is directed along the normal RN and measured by $\frac{1}{RN}$, N being as usual the point of intersection of the normal with the ray: hence the elastic force *for unit displacement measured perpendicularly to the ray*, and thus parallel to the direction of vibration, is $\frac{1}{RN^2}$.

Hence if the particle were set free after having been displaced to the point R and no other force than the evoked elasticity were acting upon it, the *initial* motion would be along the normal RN under the action of a force which is measured by $\frac{1}{RN^2}$ times the distance from the ray. Assuming that the vibration is actually and permanently perpendicular to the ray, a periodic constraining force is requisite to maintain the isochronous character of the motion: if it were possible that the constraining force and the evoked elasticity could together be always measured by $\frac{1}{RN^2}$ times the distance of the particle from the direction of the ray, we might infer by analogy with the case of sound that the velocity of transmission would be measured by $\frac{1}{RN}$, for $\frac{1}{RN}$ is the square root of the effective elastic force due to a unit displacement in the direction of vibration.

It will be found, however, that such a motion cannot actually take place: the particle will only vibrate rectilinearly if the path passes through the origin. If the particle is not moving in a line through the origin, the evoked elastic force will be constantly changing direction; for at any instant it acts parallel to the normals of the ellipsoid $a^2x^2+b^2y^2+c^2z^2=1$ at the points where a line joining the particle to the centre O meets the surface. Further the initiatory periodic constraining force is zero, not when the particle is at its position of maximum displacement, but when it is in its position of no disturbance.

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The transmission of elliptically or circularly polarised rays.

44. We have seen above (Art. 8*a*) that the simultaneous transmission of two plane-polarised rays of the same simple colour along the same line with the same velocity, but with different directions of planes of polarisation, has for general result an elliptically polarised ray of the same simple colour transmitted with the same velocity: further, the right-hand or left-hand character of the motion of the representative point round the ellipse depends only on the relation of the phases of the component rays. Hence, in general, an elliptically polarised ray, or, its special case, a circularly polarised ray, can be transmitted in any direction within a cubic crystal, or along the morphological axis of a tetragonal or hexagonal crystal; and its velocity is independent of its right-hand or left-hand character.

If the velocity of transmission of a plane-polarised ray along a given direction within a crystal is dependent on the azimuth of the plane of polarisation, we have seen (Art. 8*b*) that an elliptically or circularly polarised ray cannot result from the composition of two plane-polarised rays transmitted along that direction.

The transmission of a circularly polarised ray, however, may be possible even when that of a single plane-polarised ray is not so: for instance, a right-hand or a left-hand circularly polarised ray, but not a plane-polarised ray, can be transmitted along the morphological axis of a crystal of quartz. In such case, the velocities of transmission of a right-hand and a left-hand circularly polarised ray of the same simple colour are necessarily different: for it will be found on calculation that a right-hand and a left-hand circularly polarised ray *transmitted with the same velocity*, if superposed, are kinematically identical with a plane-polarised ray, the azimuth of the plane of polarisation of which depends solely on the relative phases of the component rays; but according to hypothesis a plane-polarised ray is incapable of transmission. Such a line will be an axis of optical symmetry, but cannot lie in a plane of general symmetry; for symmetry to the plane would require a right-hand and a left-hand ray to be transmissible with the same velocity.

In fact, if a right and left circular motion of the same radius and period are simultaneously impressed on the same particle, the resultant motion is a vibration along that diameter of the circle to which the two circular motions are symmetrical, namely, the diameter passing through the two positions of the particle which are identical for the component motions. If the two circular motions are transmitted through the medium with the same velocity, their relative phases, and thus the direc-

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tion of the line of resultant vibration, will be the same at all points of the resultant ray: if they are transmitted with unequal velocities, the line of resultant vibration will have different azimuths for different points of the ray, and the change of azimuth will be proportional to the distance between the given points. Hence it follows that if a plane-polarised ray be incident normally on a plate cut perpendicularly to the morphological axis of a crystal of quartz, the ray will not be in a state of plane-polarisation within the plate, though it will be so after emergence: the planes of polarisation of the incident and emergent rays will be inclined to each other at an angle which is proportional to the thickness of the plate.

Summary.

1. Fresnel's hypothesis—that light consists in the vibratory motion of an incompressible elastic ether—being untenable, should be abandoned as an educational instrument.

2. The later hypothesis—that light consists in the vibratory motion of a compressible elastic ether, of which the elasticity (of volume and figure) is the same for all bodies and for all directions in the same body, and of which the effective density in bi-refractive media is dependent on the direction of the vibratory motion—satisfactorily accounts for most of the known optical laws: hence such terms as "axes of optical elasticity," which relate to variation of elasticity, must be discontinued.

3. Even this more satisfactory hypothesis may only be an approximate mechanical analogy, and may eventually be found to be inconsistent with experiment in some of its optical results; hence it cannot be satisfactorily used as the *basis* of a correlation of optical characters for the student of crystals; in fact, though it appears to be fully established that electro-magnetic waves and light-waves differ only in length, an electro-magnetic disturbance seems to be inexplicable as mere vibratory motion of an elastic body.

4. On the other hand, the accuracy of Huygens' construction is now so far confirmed by experiment that it doubtless expresses a Law of Nature.

5. This being the case, it is easily seen that the velocity and polarisation of each of the two rays transmissible in a given direction in a uniaxal crystal can be simply expressed by means of the spheroid alone:—

If R be a point on the spheroid, O the centre, RN the normal, NOr a line intersecting the normal perpendicularly, the point R corresponds to a

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ray transmissible in the direction NOr with velocity $\frac{1}{OR}$ and plane of polarisation perpendicular to RN.

6. Generalisation suggests that, in the case of crystals belonging to a lower type of general symmetry, there is a similar correspondence between each ray and a point on an ellipsoid.

7. Experiment confirms the rigorous accuracy of the generalisation.

8. The surface of reference, whether a sphere, spheroid or ellipsoid, may be conveniently denoted by the term *optical indicatrix*.

9. All the optical characters can be directly deduced from the indicatrix itself, and reference to its polar reciprocal is for this purpose unnecessary: further, it is possible to develop the characters from the consideration of *rays* alone.

10. The *front* of a pencil of rays which have started simultaneously from a point is part of the *ray-surface*; in the limit, if the pencil is of small aperture and includes a given ray, the pencil-front is part of the plane which touches the ray-surface where the ray meets it: hence the pencil-front corresponding to the given ray may be briefly designated as the *ray-front*.

11. A plane passing through a ray and perpendicular to its plane of polarisation may be conveniently termed its *transverse* plane.

12. In such case, it follows that the normal to the ray-front corresponding to the ray Or lies in the transverse plane $RNOr$ and is perpendicular to OR, while the velocity of normal propagation of the front is measured by $\frac{1}{OR}$.

13. The normal RN is the direction of vibration of the ray corresponding to the point R, if the most recent hypothesis as to the properties of an elastic luminiferous ether is true.

14. The so-called primary and secondary optic axes are not axes of symmetry, nor even constant lines, of the crystal: they may with precision be denoted respectively as the *optic bi-normals* and *bi-radials*; for they are directions in which the two normals drawn from the centre to tangent planes of the ray-surface having the same direction, or the two radii vectores of the ray-surface having the same direction, are respectively coincident with each other. A crystal may still be loosely termed *biaxal*, when it is merely desired to suggest that the interference-rings shown by a plate in convergent polarised light are rudely like those

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which might be expected to be seen if the crystal had two axes, each identical in character with the optic axis of a tetragonal or hexagonal crystal.

15. By help of simple assumptions, which naturally present themselves and are consistent with all known experimental results, Fresnel's equation of the ray-surface may be deduced from the general principles of undulations, without regard to the physical character of the periodic change.

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On the Occurrence of Sapphire in Scotland.

By Professor M. F. Heddle, F.R.S.E.

[Read June 16th, 1891.]

At page 18 of Volume V. of the *Mineralogical Magazine* I gave an analysis of the red andalusite, which rarely occurs in quartzose veins in the schist of Clashnaree Hill, in Clova, Aberdeenshire.

Lately, in preparing a section of a crystal of this mineral, which section was cut at right angles to the main axis, I observed, after removing the section from the last smoothing plate, a spot which reflected light with extreme brilliancy. Examination with the lens showed that this spot, which had an intense blue colour, was most perfectly polished, while the crystal of andalusite which enclosed it hardly reflected light.

As noticed in the paper which gives the analysis, the crystals of red andalusite from this locality frequently have a central lozenge of a deeper and somewhat purple tint.

The minute blue crystal or spot lay near to the line of meeting of the two shades of red. It was surrounded by a narrow sheath of a white or pale yellow tint; and this sheath was markedly softer than even the andalusite, having been removed below the mean level of the slice by the rougher emery.

The section had to be rubbed for some time with the very finest "float-emery," before this sheath, the andalusite, and the blue crystal were brought nearly to a uniform level. It was then seen that the minute crystal was hexagonal, and that its centre was of a deeper blue than its main substance.

The above seemed to leave little doubt that it was a sapphire, and the first glance through the microscope, when the section was mounted, showed the conjecture to be a correct one.

It is a highly refractive, hexagonal crystal, of a pale blue tint, with a hexagonal deep blue centre, and an asteriated structure. Six rays of a blue, almost as intense as is the centre, pass outwards nearly to the circumference.

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Revolution, under crossed nicols, deepens the blue of the paler portions, which colour changes to a reddish or brownish yellow on further revolution.

The uniaxial system of rings is well seen. Some portions of the triangular paler spaces are slightly biaxial.

The crystal is negative.

The diameter of the crystal of andalusite is about five-eighths of an inch; the central purplish lozenge occupies about one-third of its surface. The diameter of the crystal of sapphire is about one-thirtieth of an inch.

The sheath which separates it from the andalusite is colourless, highly refractive, and formed of plates or thick fibres, which are laid on parallel to the six sides of the hexagon of sapphire.

From their position no rings can be expected.

As fibrolite of high lustre is associated with the andalusite, and as this sheath was manifestly softer than the andalusite, it may consist of the more siliceous variety of fibrolite termed xenolite, the formula of which is $2Al_2O_3$, $3SiO_2$.

The process—or the progress of the smoothing of this section—showed in a very marked manner the extreme difference in the hardness of minerals which are not far removed from each other in the numerical scale. As the sheath is probably the most siliceous variety of fibrolite, its hardness may be set down as 6. The red andalusite is very gem-like, clear, and free from all inclusions; 7·5 must be assigned to it; 9 to the sapphire. Yet at that stage of the smoothing at which the sapphire had a polish like that of a diamond, the surface of the andalusite was pitted all over, while to the lens the fibrolite looked like a dug-out trench.

In its higher grades the "the scale of hardness" is in no respect even approximately *relative*.

Probably, for the present, no better device is at our command than to ascertain, through the loss of weight, the amount abraded from a slab of orthoclase or of rock crystal by equal bulks of equally comminuted powders of the substances whose hardness is to be determined.

It must be noted, however, that the conclusions to be drawn from such a test would be to some extent vitiated by the toughness of such substances as chalcedony, jadeite, zircon and sapphire on the one hand—or by the brittleness or facile cleavage of rock crystal, topaz, euclase and diamond on the other.

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On the Optic Properties of Gyrolite.

By Professor M. F. Heddle, F.R.S.E.

[Read June 16th, 1891.]

THE specimens of gyrolite which I obtained some summers ago at the Treshinish Islands have enabled me both to make sections for the microscope and to separate the pearly lustred plates of which the characteristic orbicular masses are built up.

In both, but most perfectly in the latter, I have been able to get the optic rings. This is, of course, only preliminary to the correct determination of the crystalline faces, as promised by Professor Descloizeaux.

All the first plates gave an apparently uniaxial figure. By employing a thiner plate I however found that the figure was biaxial, but that the axial divergence was only 2° to 3°. On the outer side of each loop there is a pale but brilliant field of blue colour. Professor Descloizeaux had already announced to me that the mineral was negative; this I corroborate.

The sections of orbicular gyrolite are among the most splendid of polariscopic objects, resembling a circularly-opened fan, of most brilliant and abruptly contrasted colours.

The mutual cohesion of the plates is so feeble that only the smaller druses—those in which in an ordinarily-sized section the rock forms the whole circumference—can be utilised. Fortunately this mineral is invariably in the centre of the druse-faröelite and mesolite, neither of which is so fragile, underlying it.

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Note on the Occurrence of Melanterite in the Upper Eocene Strata of the Thames Basin.

By Rev. A. Irving, B.A., D.Sc.

Senior Science Master of Wellington College, Berks.

[Communicated by the Secretary. Read April 14th, 1891.]

UNDER the name of "Copperas" Bristow describes melanterite as occurring, among other localities, in the Bagshot formation in Dorsetshire (Glossary of Mineralogy). In Naumann-Zirkel's Mineralogie (p. 491) it is stated that it seldom occurs distinctly crystallised in Nature. Its derivation from iron pyrites, by the combined action of water and the atmospheric oxygen carried into the ground in solution in rain-water, is well known.

The purpose of the present note is to record its occurrence in the Upper Eocene or Bagshot strata of the London Basin. Last winter a well was dug near Wellington College Station on the South-Eastern Railway into the uppermost beds of the so-called Bracklesham or Middle Bagshot. At this horizon beds of sand and clay, often constituting a very good "brick-earth," when well mixed, are of common occurrence. In the present instance thin bands of a very hard puce-coloured clay were interlaminated with thin bands of rather coarse sand, which was coloured in many places with a bright green. Grains of glauconite might be detected, but the generally-diffused green colour of the sand-layers could not be attributed to the presence of that mineral; the colour, moreover, was a bottle-green rather than the dark olive-green of glauconite. The beds in question were met with at a depth of 5 to 13 ft. from the surface of the ground, and contained layers of lignite, a common accompaniment of FeS_2 in this formation.

A considerable quantity of the material of the beds described was reserved and exposed to atmospheric desiccation indoors. The result was that in a few weeks the diffused green colour disappeared for the most part, giving place to a rusty brown, as sulphate of iron is known to do when

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exposed to the air for a time, through the peroxidation of the base of the salt. This change at once suggested the presence of a native hydrated sulphate of iron; and this proved to be the case, ordinary qualitative analysis showing the presence of both iron and sulphuric acid.

A partial quantitative analysis was then made of a portion of the sandy material collected from the small patches which still retained a distinctly green colour. In order to avoid the risk of any loss of sulphuric acid from the substance by dry distillation it was thought best not to dry the substance at such a temperature as should secure the expulsion of all the water before weighing the sample dealt with; preliminary weighing was therefore dispensed with. The sample was digested in excess of distilled water for a day or two, then filtered.

The *residue* from this was dried at 120° C. in an ordinary drying-oven, and on being weighed gave 1·695 grams of a clean gritty sand, with a trace of argillaceous and carbonaceous material. The green tint had entirely gone even before it was dried.

In the *filtrate* the sulphate was precipitated by $BaCl_2$, with the usual precautions and 0·16 gram of $BaSO_4$ was obtained. By a simple calculation the equivalent weight of anhydrous $FeSO_4$ was found to be 0·104 gram. Adding now $7H_2O$ for the water of hydration of the native mineral, we get 0·19 gram of the hydrated salt as the equivalent of the 0·104 gram of the anhydrous salt. This gives 12·4 per cent. nearly as the proportion of the mineral melanterite in the sample examined.

The result is interesting, as throwing light in some cases upon the origin of the diffused green colour met with at various horizons in the sands of this and other geological formations; and this must be the excuse for the appearance of the present short note.

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(1.) *Tysonite and Bastnäsite;* (2.) *Meteoric Iron from Indian Valley Township, Virginia;* (3.) *Anatase;* (4.) *Sapphire.*

By Geo. F. Kunz.

[Read June 16th, 1891.]

(1.) *Tysonite and Bastnäsitè from Crystal Park, near Mainton Springs, Colorado.*

About two years ago Mr. T. A. Herstand of Mainton Springs, Colorado, made a remarkable find of tysonite and bastnäsite at Crystal Park, near Mainton Springs, Colorado. The entire find consisted of one crystalline cleavable mass of tysonite, covered with bastnäsite, weighing in all fully six kilograms. It was found in a coarsely crystalline granite, and no other deposit has been discovered subsequently, although considerable search has been made by various prospectors. Up to the time of this find all the tysonite discovered in Colorado has not amounted to more than 50 grams.

The tysonite was principally of a rich cinnamon-brown colour with a perfect basal cleavage, and frequently contained patches from one to three cm. in diameter which were entirely transparent.

In the fissures of both minerals is found a creamy white pulverulent mineral which is evidently an alteration product of the bastnäsite.

Both the tysonite and bastnäsite exhibit very pronounced absorption spectra when viewed with a spectroscope; sections of both minerals cut parallel to the basal plane show the same uniaxial interference figure, which suggests that the two minerals may belong to the same crystalline system, and that possibly the bastnäsite is either only an alteration product of the tysonite, or a differently-coloured variety of the same mineral.

(2.) *An undescribed mass of Meteoric Iron from Indian Valley Township, Floyd County, Virginia.*

This mass of meteoric iron was found in Indian Valley Township in the spring of 1887, and weighs 14 kilos; it is a cubic iron, having a very marked crystalline structure, and shows the Neumann lines on etching with dilute nitric acid.

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It furnished Mr. L. G. Eakins, of the U. S. Geological Survey, the following result on analysis :—

Iron	...	...	93·59
Nickel	...	...	5·56
Cobalt	...	...	·53
Copper	...	...	trace
Phosphorus	...	...	·27
Sulphur	...	...	·01
Silica	...	...	trace
			99·96

The surface of the iron is very much corroded, and it is certainly not a recent fall.

(3.) *Octahedrite* (*Anatase*) *from near Placerville, Eldorado County, California.*

Implanted on some highly interesting quartz crystals with rather unusual enclosures I observed some crystals of a mineral new to the Pacific Coast, and one which, though frequently observed in Europe, is yet of rather rare occurrence in North America—namely anatase.

Up to the present time only two specimens have come to hand; in both the crystals were implanted on the quartz and were highly splendent; on one specimen the crystals were a rich honey-brown by transmitted light; on the other a deep metallic blue. In size none were longer than 8 mm. In form they showed the common habit of the Swiss crystals, namely the pyramid {111} surmounted by a more obtuse pyramid.

The anatase was found in a vein of quartz crystals, varying from the size of a finger up to masses weighing 80 or 90 lbs.

Some of the quartz crystals were of more than usual interest—pellucid masses weighing 50 lbs. each; others enclosed chlorite deposited in successive layers; but the most interesting were those which enclosed, at a depth of from three to ten mm. from the surface of the crystal, and arranged according to the lines of growth, spherical masses (often silvery white), three to five mm. in diameter, consisting of crystallised aggregates of ankerite or siderite. The crystalline form of the latter was rhombohedral, and where exposed they had oxidised to a rusty-brown.

(4.) *The Sapphire Deposits of the Northern Missouri River, near Helena, Montana.*

It was found, on a visit to this locality, that the sapphires are generally flat hexagonal crystals without prism faces, or crystalline fragments.

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They vary in colour from light blue, lavender, light red, light green, to almost bottle green, and are very dichroic, appearing blue or green when viewed across the prism, but pink or bright red when viewed along the length of the crystal. They afford very brilliant gems with a remarkable lustre; but no true (sapphire-) blue or true (ruby-) red crystals have been observed from this locality.

The greatest deposits are between Eldorado Bar, Ruby Bar, and other bars along the Missouri River, for a distance of six miles, the central point being 16 miles from Helena.

Until recent years they have not been systematically mined, but have been found in the sluices and pans in the mining for gold, with which they are often found associated in a layer of fine glacial gravel immediately overlying the old slate rock.

In the deposit at Ruby Bar I observed, associated with the gold and the gravel, a mastodon tusk about 3 ft. in length.

The associated minerals were rutile, topaz in brilliant white modified crystals resembling those from Durango, stream tin, curious concentric masses of limonite pseudomorphous after pyrites, cyanite in broken crystals, chalcedony, calcite, and fine ruby-red garnet. From these the locality derives its name.

At Ruby Bar the sapphires were observed in a vein of eruptive rock 6 ft. wide, cutting the green slate. The rock is very much altered, and in it were found, associated with the sapphires, ruby red pyrope garnets and sanidine felspars.

It is evident that all the sapphires found on the bars were derived from some such rock and were worn out during the glacial period.

Mr. H. Miers, of the Natural History Museum, London, reports that the rock is a vesicular mica-augite-andesite.

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* Denotes an *Abstract* or *Review*.

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Errata in Vol. IX.

p. 262, line 18 from top,

for "*Krystalskelette*" *read* "*Krystallskelette.*"

p. 274, line 4 from bottom,

for "upper" *read* "right-hand."

p. 327, line 12 from bottom,

for "$lx'+my'+zz'$" *read* "$lx'+my'+nz'$."

p. 328, line 6 from bottom,

for "*Ot*" *read* "*Of.*"

p. 331, line 13 from top,

for "rays" *read* "front-normals."

p. 387, lines 1 and 2 from top,

for "$\frac{1}{ON}$" *read* "$\frac{1}{RN}$"

p. 391, line 12 from top,

for "thiner" *read* "thinner."

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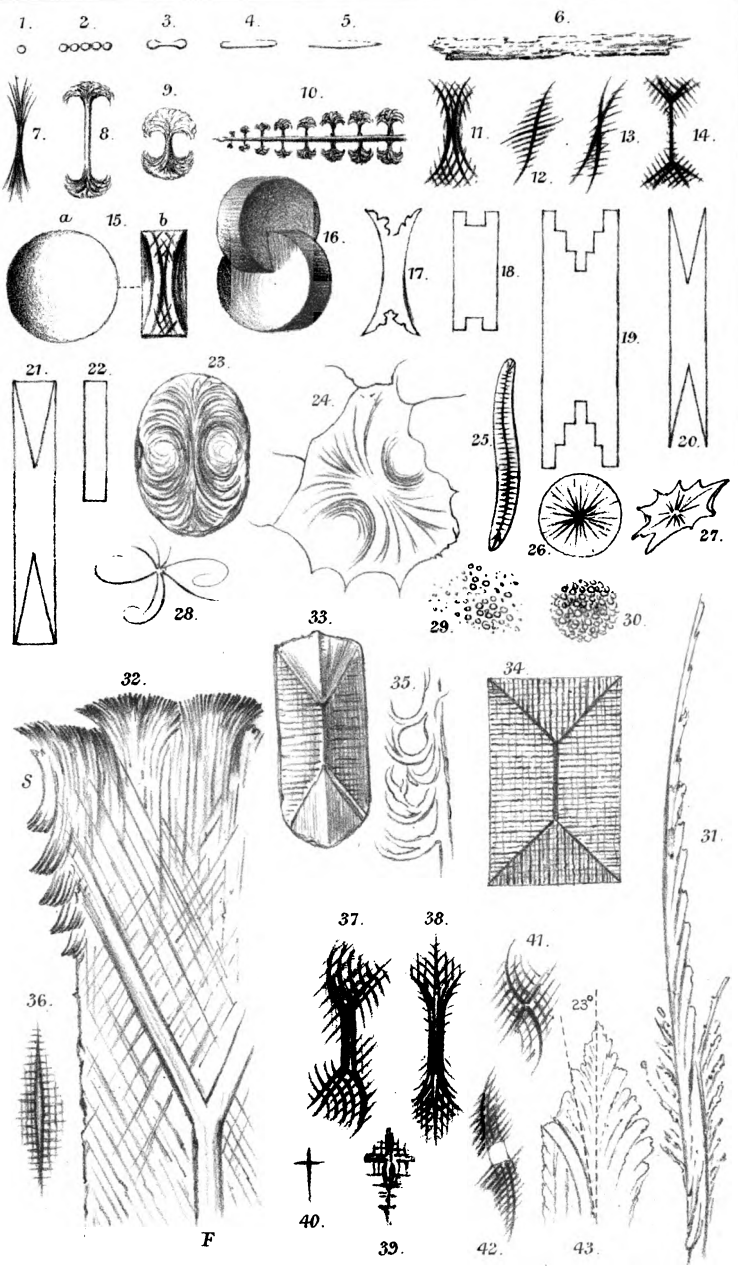

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GENERAL NOTICES.

Members desiring to propose Candidates for Election are requested to send the names and qualifications of the Candidates to the General Secretary: all communications for the Magazine should also be sent to him.

Authors alone are responsible for the views set forth in their respective papers.

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EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, November 5th, 1889.

R. H. Scott, Esq., M.A., F.R.S., President, in the Chair.

Dr. Hugo Müller was elected a member of the Editing Committee (in place of the retiring member, Professor Kinch).

An offer made by Professor Lewis to undertake the charge of the Library was accepted with thanks.

The following dates of meeting during the year 1890 were fixed:—January 14, March 18, May 20, November 11.

ANNIVERSARY MEETING.

Held in the Apartments of the Geological Society, November 5th, 1889.

H. R. Scott, Esq., M.A., F.R.S., President, in the Chair.

The following Report of Council was read and approved:—

REPORT.

The Balance Sheet for the year ending December 31, 1888, which was issued with No. 38 of the Journal, showed that the state of finances was not unsatisfactory. The excess of Assets over Liabilities was £215. 0s. 7d.

During the session 1888-1889 three ordinary Members have been elected, and a fourth has been reinstated; four Members (three of them resident abroad) have resigned, and one Member (Mr. Readwin) has been removed by death. The Society has to regret the decease of one of its most distinguished Corresponding Members, Professor Kjerulf. An obituary notice will appear in the Journal.

Five meetings have been held, all in London: the first was held in the Museum of Practical Geology, the others in the Apartments of the Geological Society.

Three numbers of the Journal have been issued: No. 38 in March, No. 39 in May, and No. 40 in October. No. 38 contained papers on Scotch Minerals, by Professor Heddle, Professor Macadam and Mr. Morrison, and a description of a new form of

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microscope, by Mr. Dick ; the contents of No. 39 were various, and included a paper, by Professor Judd, on the Processes by which a Plagioclase-felspar is converted into a Scapolite. Of the papers contained in No. 40, attention may be called to a detailed discussion of the Meteorites of Atacama, by the Secretary ; and to a paper, by Professor McKenny Hughes, on the manner of occurrence of Beekite. It may be added, that the cost of two of the plates in the above numbers has been defrayed by the authors of the corresponding papers, Professor Judd and the Secretary.

The Council would again remind the Society, that, for the proper maintenance of the Journal, it is desirable that there should be an increase in the number of Members who contribute papers. An addition to the number of Members of the Society would render a more frequent issue of the Journal financially practicable.

The following were elected Officers and Council for the ensuing year :—

President. R. H. Scott, M.A., F.R.S.

Vice-Presidents. Rev. S. Haughton, M.D., F.R.S.
Hugo Müller, Ph. D., F.R.S.

Treasurer. Rev. Professor T. G. Bonney, D.Sc., F.R.S.

General Secretary. L. Fletcher, M.A., F.R.S.

Foreign Secretary. T. Davies, F.G.S.

Council.
Prof. A. H. Church, M.A., F.R.S.
Townsend M. Hall, F.G.S.
Major-Gen. C. A. McMahon, F.G.S.
J. Stuart Thomson.
C. A. Burghardt, Ph.D., F.C.S.
H. A. Miers, M.A., F.G.S.
R. H. Solly, M.A., F.G.S.
J. M. Thomson, F.R.S.E., F.C.S.
P. Dudgeon, F.R.S.E.
Prof. A. H. Green, M.A., F.R.S.
A. Harker, M.A., F.G.S.
Prof. W. J. Lewis, M.A., F.C.S.

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Mr. B. Kitto, F.G.S., and Mr. F. W. Rudler, F.G.S., were re-elected Auditors.

A vote of thanks to Mr. Miers for his Index to Mineralogical Papers was passed.

A vote of thanks to Professor Lewis for his offer to take charge of the Library was passed.

A vote of thanks to the Geological Society for its kindness in allowing the Mineralogical Society the use of a room for its meetings was passed.

A vote of thanks to the retiring Members of the Council (Professor Judd, Professor Kinch, Professor Macadam, and Mr. Teall) was passed.

The following papers were read :—

"On the Hemimorphism of Stephanite," by H. A. Miers, M.A. (page 1.)

"On the Crystalline form of Kaolinite," by the same. (page 4.)

"On Oxide of Zinc from a Blast Furnace," by J. T. Cundall, F.C.S., and A. Hutchinson, B.A. (page 5.)

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EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, January 14th, 1890.

R. H. Scott, Esq., M.A., F.R.S., President, in the Chair.

Mr. J. C. Horobin, B.A., of Emmanuel College, Cambridge, and The College, Homerton, E., and Mr. A. Hutchinson, B.A., of Christ's College, Cambridge, were elected Members of the Society.

The death of Lord de Blaquière, Trustee and Member of the Society, was announced.

Professor N. S. Maskelyne, M.P., F.R.S., was elected to the vacant Trusteeship.

GENERAL MEETING.

Held in the Apartments of the Geological Society, January 14th, 1890.

R. H. Scott, Esq., M.A., F.R.S., President, in the Chair.

The following papers were read :—

"On New Localities for Zeolites." By Professor M. F. Heddle, M.D., F.R.S.E.

"On Zinc-Sulphide encrusting Stibnite: Analyses of Stephanite and Polybasite." By G. T. Prior, M.A. (page 9.)

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, March 18th, 1890.

R. H. Scott, Esq., M.A., F.R.S., President, in the Chair.

The resignation of Mr. J. W. Crocker, and the death of Mr. E. F. Morton, both Associates of the Society, were announced.

GENERAL MEETING.

Held in the Apartments of the Geological Society, March 18th, 1890.

R. H. Scott, Esq., M.A., F.R.S., President, in the Chair.

The following papers were read :—

"On the Meteoric Iron of Tucson." By Mr. L. Fletcher, M.A., F.R.S. (page 16.)

"An Account of a Visit to the Calcite-Quarry in Iceland." By Mr. J. L. Hoskyns-Abrahall. (Communicated by the Secretary.) (page 179.)

"Mineralogical Notes." By Mr. H. A. Miers, M.A., F.G.S. (page 182.)

Specimens were exhibited in illustration of the papers of Mr. Abrahall and Mr. Miers: also a specimen of the barium sulphate of Perkin's Mill, sent by Dr. G. C. Hoffmann, of the Geological Survey of Canada.

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EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, May 20th, 1890.

R. H. Scott, Esq., M.A., F.R.S., President, in the Chair.

The audited Balance Sheet for the year 1889 was submitted, and ordered to be issued with the next number of the Journal (page vii.)

A proposal to exchange publications with the Editor of the *Giornale di Mineralogia* was accepted.

GENERAL MEETING.

Held in the Apartments of the Geological Society, May 20th, 1890.

R. H. Scott, Esq., M.A., F.R.S., President, in the Chair.

The following papers were read:—

"On the Mexican Meteorites, with especial regard to the supposed occurrence of wide-spread Meteoritic Showers. By Mr. L. Fletcher, M.A., F.R.S. (page 91.)

"On Svecium, a supposed new metallic element from the Hausmannite- and Braunite-mine, Sjögrufvan." By Mr. L. J. Igelström. (Communicated by the Secretary.)

"Notes on Bowenite, or Pseudo-Jade, from Afghanistan." By Major-General C. A. McMahon, F.G.S. (page 187.)

"On the Relations between the Gliding Planes and Solution Planes of Augite." By Professor J. W. Judd, F.R.S. (page 192.)

Crystals of Corundum were exhibited by Professor Judd, and specimens of the Afghan Bowenite by Major-General McMahon.

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Mineralogical Society—Abstract of Receipts and Payments from 1st January to 31st December, 1889.

RECEIPTS.

	£	s.	d.
Balance from year 1888	13	1	1
Subscriptions:—(1) in advance	1	1	0
,, (2) current	73	8	6
,, (3) in arrear	13	18	0
Entrance Fees and Compositions	11	11	0
Sale of Publications	32	0	0
Repayment for Authors, extra copies	5	3	10
Dividends on Stock	6	11	7
	£156	15	0

PAYMENTS.

	£	s.	d.
Printing and Stationery	86	9	9
Care of Stock of Publications and Insurance (1888)	5	9	0
Illustrations	12	8	0
Attendance at Meetings	3	16	6
Editorial and Clerical Expenses (1888)	16	16	0
Preparation of list of contents of Library	0	12	6
Postages, Parcels, &c.	5	1	1
Investments	13	11	7
Putting four volumes in covers	0	5	6
Balance	12	5	1
	£156	15	0

Examined and compared with the vouchers and found correct. (Signed)

25*th March*, 1890.

BENEDICT KITTO,
F. W. RUDLER, } *Auditors.*

LIABILITIES.

	£	s.	d.
Williams & Strahan, Printing, &c.	57	18	2
Received in advance (Subscription)	1	1	0
,, ,, (Sale of Journal)	0	19	0
Excess of Assets over Liabilities	220	8	5
	£280	6	7

Number of Life Members 30.

ASSETS.

	£	s.	d.
Subscriptions for 1887-9 unpaid	12	12	0
Stock in 2¾ Per Cent. £251 10s. 8d. at 97⅞	244	6	0
Proportion of Interest on Stock unpaid	1	13	9
Sale of Journal:—(1) due from the Publishers	14	4	3
,, (2) due on Office Account	3	16	1
Due for Authors' extra copies	3	14	6
	£280	6	7

The Stock of Publications and the Library are not included in the above assets.

(Signed)

L. FLETCHER,

General Secretary.

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EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, November 11th, 1890.

R. H. Scott, Esq., M.A., F.R.S., President, in the Chair.

Mr. S. R. Adcock and Mr. W. Rich, both of Rio Tinto, and Mr. F. G. Shaw were elected Members of the Society.

The resignations of Mr. J. E. Drew and Mr. G. F. Martyn, both Associatesof the Society, were announced.

The following dates were selected for the Meetings to be held during the year 1891:—January 27, April 14, June 16, November 10 (Anniversary).

ANNIVERSARY MEETING.

Held in the Apartments of the Geological Society, November 11th, 1890.

R. H. Scott, Esq., M.A., F.R.S., President, in the Chair.

The following Report of Council was read and approved:—

REPORT.

The Balance Sheet for the year ending December 31, 1889, which was issued with No. 42 of the Journal, showed that the state of finances was not unsatisfactory. The Assets (exclusive of the Stock of Publications and the Library) show an excess over Liabilities of £220 8s. 5d.: in this connection it may be mentioned that the number of Members who have compounded for their Annual Subscription is 30.

During the session 1889-90 five ordinary Members have been elected. On the other hand, the Society has to regret the loss by death of one Member, Lord de Blaquière, who for many years has acted as one of the Trustees for the invested funds of the Society, and of one Associate, Mr. E. F. Morton; one Member and three Associates have resigned, and the name of one Member has been removed from the list for non-payment of subscriptions: it may be added that four Members and one Associate are without known address.

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The Council has great pleasure in reporting that Professor N. S. Maskelyne, M.P., F.R.S., has consented to act as Trustee, in place of Lord de Blaquière, deceased.

Four meetings have been held, all in London, and (by kind permission) in the Apartments of the Geological Society, Burlington House.

Though only two numbers of the Journal have been issued during the session, they exceed in number of pages the three numbers issued in the preceding year. No. 41, which appeared in April, contained papers on the Hemimorphism of Stephanite and the Crystalline Form of Kaolinite, by Mr. Miers; on artificially crystallised Zinc Oxide, by Messrs. Cundall and Hutchinson; on Zinc Sulphide, Stephanite and Polybasite, by Mr. Prior; but was chiefly remarkable for the Index to the Mineralogical and Petrographical Papers of 1887, for which the Society is indebted to Mr. Miers. This Index, like those of which it is a continuation, is obviously the result of much patient industry on the part of its author, and cannot fail to be of great service to those who are engaged in mineralogical research. No. 42, which appeared in August, contained a short, but interesting account of a visit to the Calcite Quarry in Iceland, by Mr. Hoskyns-Abrahall; the description of a new mineral species, Sanguinite, by Mr. Miers; notes on a hard form of Serpentine, or Pseudo-jade, from Afghanistan, by Major-General McMahon; and a discussion of the Relations between the Gliding-planes and Solution-planes of Augite, by Professor Judd. The greater part of the number is occupied by Mr. Fletcher's paper relative to the Mexican Meteorites. This paper, taken in conjunction with one in the preceding number, gives as complete an account of the history and distribution of the Mexican Meteorites as can be got from the examination of the specimens and literature at present available for a student in this country. The Council begs leave to report that the Library of the Society has been removed to Cambridge, and that any of the books may be borrowed by Members on application to the Librarian, Professor Lewis.

The Council still looks foward to a more frequent issue of the Journal, but the present income of the Society is not such as to warrant any increase of the expenditure.

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The following were elected Officers and Council for the ensuing year :—

President. R. H. Scott, M.A., F.R.S.

Vice-Presidents. Rev. Prof. S. Haughton, M.D., F.R.S.
Hugo Müller, Ph.D., F.R.S.

Treasurer. Rev. Prof. T. G. Bonney, D.Sc., F.R.S.

General Secretary. L. Fletcher, M.A., F.R.S.

Foreign Secretary. T. Davies, F.G.S.

Council.
C. A. Burghardt, Ph.D., F.C.S.
H. A. Miers, M.A., F.G.S.
R. H. Solly, M.A., F.G.S.
Prof. J. M. Thomson, F.R.S.E., F.C.S.
P. Dudgeon, F.R.S.E.
Prof. A. H. Green, M.A., F.R.S.
A. Harker, M.A., F.G.S.
Prof. W. J. Lewis, M.A., F.C.S.
Prof. Grenville Cole, F.G.S.
T. W. Danby, M.A., F.G.S.
John Horne, F.R.S.E., F.G.S.
Frank Rutley, F.G.S.

Mr. B. Kitto, F.G.S., and Mr. F. W. Rudler, F.G.S., were re-elected Auditors.

Votes of thanks were passed to the Geological Society for the use of its Apartments for the Meeting, and to the retiring Members of the Council (Prof. Church, Mr. Hall, Maj.-Gen. McMahon and Mr. J. S. Thomson).

The following papers were read :—

"Twins of Marcasite in regular disposition upon Cubes of Pyrites," by C. O. Trechmann, Ph.D., F.C.S. (page 209.)

"Notes on Cassiterite," by R. H. Solly, M.A., F.G.S. (page 199.)

"Note on Ullmannite," by H. A. Miers, M.A., F.G.S. (page 211.)

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EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, January 27th, 1891.

R. H. Scott, Esq., M.A., F.R.S., President, in the Chair.

The audited Balance Sheet for the year 1890 was submitted and ordered to be issued with the next number of the Journal (page xiii.).

M. J. Gorham, M.R.C.S., of Tonbridge, was elected a Member of the Society.

Mr. H. A. Miers was elected a Member of the Editing Committee (in place of the retiring Member, Mr. T. Davies).

GENERAL MEETING.

Held in the Apartments of the Geological Society, January 27th, 1891.

R. H. Scott, Esq., M.A., F.R.S., President, in the Chair.

The following papers were read :—

"On an Eclogite from Loch Duich." By J. J. H. Teall, M.A., F.R.S. (page 217.)

"On a Micro-granite containing Riebeckite from Ailsa Craig." By the same. (page 219.)

"On Occurrences of Riebeckite in Britain." By Prof. Grenville A. J. Cole, F.G.S. (page 222.)

"On a Rapid Method for the accurate Recognition of Sulphides, Arsenides, Antimonides, and Double Compounds of these Elements with Metals." By C. A. Burghardt, Ph.D. (page 227.)

"On a System for constructing Crystal Forms by the plaiting of their Zones." By J. Gorham, M.R.C.S. (page 235.)

Specimens of minerals and crystal models were exhibited in illustration of the above papers.

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Mineralogical Society—Abstract of Receipts and Payments from 1st January to 31st December 1890.

RECEIPTS.	£	s.	d.
Balance from year 1889	12	5	1
Subscriptions:—(1) in advance	4	9	0
,, (2) current	72	2	6
,, (3) in arrear	7	18	6
Entrance Fees and Compositions	3	3	0
Sale of Journal	18	11	1
Repayment for Authors' extra copies	15	19	6
Dividends on Stock	6	18	3
Illustration paid for by Mr. Hutchinson	0	12	6
	£141	19	5

PAYMENTS.	£	s.	d.
Printing and Stationery	102	11	11
Illustrations (1890)	7	9	0
Editorial and Clerical Expenses (1890)		Nil	
Purchase of Journal	1	10	0
Insurance of Stock of Publications	1	5	0
Postages, Parcels, &c.	12	4	9
Investments	6	18	3
Fees in connection with Change of Trustee	1	15	8
Carriage of Library to Cambridge	0	19	6
Attendance at Meetings, 1890	1	17	0
Balance	5	8	4
	£141	19	5

Examined and compared with the vouchers and found correct. (Signed)

1891.

BENEDICT KITTO,
F. W. RUDLER, } *Auditors.*

LIABILITIES.	£	s.	d.
Williams & Strahan, Printing, &c.	55	10	11
Received in advance (1) Subscriptions	4	9	0
,, ,, (2) Sale of Journal	0	1	11
Excess of Assets over Liabilities	220	0	2
	£280	2	0

Number of Life Members is 30.

ASSETS.	£	s.	d.
Subscriptions for 1888-90 unpaid	5	5	0
Stock in 2¾ per Cent. £258 12s. 7d. at 95¾	247	12	9
Interest on Stock (unpaid)	1	13	5
Sale of Journal:—(1) due from the Publishers	17	18	0
,, ,, (2) due on Office Account	2	4	6
Balance as above	5	8	4
	£280	2	0

The Stock of Publications and the Library are not included in the above assets.

(Signed)

L. FLETCHER,

General Secretary.

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EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, April 14th, 1891.

R. H. Scott, Esq., M.A., F.R.S., President, in the Chair.

Dr. John William Evans, F.G.S., and Mr. Alfred E. Tutton, F.C.S., were elected Members.

Thanks were voted to Mr. Solly for the gift of three figures, and to Mr. Miers for the loan of three blocks, for use in the illustration of their respective papers in No. 48 of the Journal.

GENERAL MEETING.

Held in the Apartments of the Geological Society, April 14th, 1891.

R. H. Scott, Esq., M.A., F.R.S., President, in the Chair.

Thirteen Members and two Visitors were present.

The following papers were read :—

"On the Occurrence of an aluminous Serpentine (Pseudophyte) with flint-like appearance near Kynance Cave." By Howard Fox, Esq., F.G.S. (Communicated by Mr. Teall.) (page 275.)

"Note on the Occurrence of Melanterite in the Upper Eocene Strata of the Thames Basin." By the Rev. A. Irving, B.A., D.Sc. (Communicated by the Secretary.) (page 392.)

"Notes on various American Minerals, including Bastnäsite, Oligoclase, Quartz, Sapphire, and a Meteoric Iron." By G. F. Kunz, Esq. (page 394.)

"On the Devitrification of Cracked and Brecciated Obsidian." By Professor Grenville A. J. Cole, F.G.S. (page 272.)

"Notes on Crystallites." By F. Rutley, Esq., F.G.S. (page 261.)

"On the Method of Observing the Absorption-spectra of Minerals with the aid of the Microscope." By Allan Dick, Esq. (Communicated by the Secretary.)

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EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, June 16th, 1891.

R. H. Scott, Esq., M.A., F.R.S., President, in the Chair.

The following Members were selected for nomination as Officers and Members of Council at the Annual Meeting :—

President. Prof. N. S. Maskelyne, M.P., F.R.S. (in place of Mr. Scott.)

Treasurer. Mr. F. W. Rudler, F.G.S. (in place of Professor Bonney.)

Council. Rev. H. P. Gurney, M.A., F.G.S.
Prof. G. D. Liveing, M.A., F.R.S.
Maj.-Gen. C. A. McMahon, F.G.S.
Mr. J. J. H. Teall, M.A., F.R.S. (in place of the retiring members Dr. Burghardt, Mr. Miers, Mr. Solly, and Prof. J. M. Thomson.)

GENERAL MEETING.

Held in the Apartments of the Geological Society, June 16th, 1891.

R. H. Scott, Esq., M.A., F.R.S., President, in the Chair.

Eight members were present.

The following papers were read :—

"On the Occurrence of Sapphire in Scotland." By Prof. M. Forster-Heddle, M.D., F.R.S.E. (Page 389.)

"On the Optical Properties of Gyrolite." By the same. (Page 391.)

"On the Optical Indicatrix and the Transmission of Light in Crystals." By L. Fletcher, M.A., F.R.S. (Page 278).

A circular of which the following is a translation has been received from Dr. Aristides Brezina. Director of the Mineral Department, Natural History Museum at Vienna.

On the 26th of September a young man was captured in the Mineralogical Department of the Natural History Museum at Vienna, who had managed to conceal himself in the parapet of a window shortly before the museum was closed ; he was found to have upon him a loaded revolver,

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together with files and other burglarious implements; in his possession was also found a collection of about 600 gems, partly cut and partly rough stones.

The thief, who had a passport from Berlin under the name of Hugo Kahn, and also gave the names of Krony, Kronek, Karnak, Kronicsalsky, is 24 years old, 5 ft. 7 in. in height, thin, with somewhat long handsome profile, brown complexion, dark hair, gray eyes, thin brown beard, altogether superior appearance; he has made several journeys in Germany, France, Switzerland, and Italy. Between the middle of July and beginning of September he has passed through Pyrmont, Ems, Strassburg, Basel, Milan, Genoa, Nice, Monaco, Genoa and Venice, to Vienna, and claims to have bought the majority of the stones (of which he does not know the names with the exception of the Rock Crystal) from a barber in Marseilles.

It would be desirable to discover the former possessor of all or some of these stones, and the following list is given, with the request for information regarding their previous habitat.

Euclase: 1 crystal, 2 cm. in length; 1 cleavage fragment 1 cm. across.

Emerald: 6 small crystals from Muso; 1 moderate-sized crystal of inferior colour with calcite from Muso; 1 large Russian crystal.

Beryl: 3 large aqua marines, partly cut; 1 green crystal with polished faces; 1 yellow crystal; 3 small crystals; 1 aqua-marine cut as a brilliant.

Chrysoberyl: 6 small catseyes; 8 crystals.

Spinel; indigo blue, cut as a brilliant; about 30 small crystals from Ceylon, 1 small crystal on the matrix from North America.

Star Sapphire, cut en cabochon.

Topaz: 2 rose-red crystals; 36 Schneckenstein topazes; 4 large yellow Brazilian topazes; 4 water-worn crystals; 7 crystals from different localities.

Chrysolite: 7 crystals, 2 cut as brilliants.

Zircon: 1 from Canada; about 50 small zircons from Frederiksvärn and Miask.

Tourmaline: 1 crystal from Prävali; 4 from Elba; 1 small clear crystal with black termination; 50 black crystals; 1 clear green from Binnenthal.

Idocrase: 4 from Ala; 1 from Vesuvius.

Axinite: 3 from Dauphiné; 1 from Scopi.

Garnet: Dodecahedron with icositetrahedron; about 40 Hessonite pebbles.

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Quartz: 800 Marmora diamonds; 8 Flèches d'Amour, polished; 7 Carrara crystals; 1 complete crystal with curved edges; 4 gray to black crystals; 10 crystals (various); 6 polished fossil woods.

Opal: 1 fire-opal; 3 milk-opals; 2 polished wood-opals.

Obsidian or Moldawite, cut as brilliant, broken in two.

Magnetite: black grain.

Strass: 2 large cherry-red brilliants.

Doubtful: 7 small stones.

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